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DEVELOPMENT OF A COMPUTER MODEL OF THE FACTORS WHICH INFLUENCE HIGH SCHOOL STUDENTS TO CONTINUE OR DISCONTINUE THEIR EDUCATION.

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THE PROBLEM OF THIS EFFORT INVOLVED--(1) THE DEVELOPMENT OF A WORKABLE AND EMPIRICALLY GROUNDED THEORY OF COMMUNICATION AND DECISION-MAKING RELATIVE TO STUDENT TRANSITION FROM HIGH SCHOOL TO COLLEGE, AND (2) THE DESIGN AND EMPIRICAL TESTING BY COMPUTER MANIPULATION OF A FORMAL MODEL TO CHARACTERIZE THIS THEORY, USING THE "MARKOV CHAIN PROCESS." AN EMPIRICAL SETTING, A CONCEPTUAL FRAMEWORK, AND TERM DEFINITIONS WERE PROVIDED IN DESCRIBING THE COMMUNICATION-DECISION BEHAVIOR AMONG HIGH SCHOOL STUDENTS. GIVEN THE CONCEPTUAL FRAMEWORK, THE NEXT STEP WAS TO CHOOSE AN "OPTIMAL" STRATEGY (IN RELATION TO THE STATE OF INFORMATION) FOR THE MODEL DESIGN. NEXT, THE "TIME-DEPENDENT" COMMUNICATION BEHAVIOR OF STUDENTS IN RELATION TO THE STATE OF DECISION WAS EXAMINED IN TERMS OF TWO POSSIBLE SOLUTIONS--(1) A COMMUNICATION-DECISION MODEL WITH CONSTANT TRANSITION MATRICES OR INCREMENTAL BEHAVIOR IN A SEQUENCE OVER TIME, AND (2) A MODEL WITH TIME-VARYING PARAMETERS OR TRANSFORMATIONAL INFORMATION OVER TIME. FROM THIS ACTIVITY, A MARKOVAN TIME-VARYING, COMMUNICATION-DECISION MODEL WAS DEVELOPED. A DIGITAL COMPUTER PROGRAM, USING FORTRAN LANGUAGE AND PROVIDING RANDOM OUTPUTS, WAS THEN DEVELOPED FOR MODEL SIMULATION. THE COMPUTER GENERATED A NUMBER OF OUTCOMES WHICH SHOWED HOW LONG IT TOOK A STUDENT TO ARRIVE AT A "DECISION" AND WHAT KIND OF DECISION WAS MADE, NAMELY, TO GO OR NOT GO TO COLLEGE. (JH)

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DEVELOPMENT OF A COMPUTER MODEL OF THE FACTORS WHICH INFLUENCE HIGH SCHOOL STUDENTS TO CONTINUE OR DISCONTINUE THEIR EDUCATION

by

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I.

TRANSITION FROM HIGH SCHOOL TO COLLEGE:

A STATEMENT OF THE PROBLEM[1]

The purpose of this paper is to describe a communication-decision process which seeks to overcome some of the limitations of traditional statistical techniques employed in the analysis of factors effecting the student transition from high school to college and to resolve some of the inconsistencies and paradoxes uncovered by education researchers in their studies of college-going decision-making.

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[1] The author is indebted to Dr. Harold D. Holder, assistant professor, Baylor University, who was the research associate in this project. Professor Holder, among other things, carried the heavy burden of directing the computer programming, analysis, and testing. He was responsible for writing the simulation program, and devoted long hours debugging the program, making necessary modification, and checking the printout data. More than that, Dr. Holder helped solve problems of mathematical analysis, model design, and theory formulation. He also conducted the analysis of empirical data upon which this study is based.

The author is also grateful to Professor Sakari T. Jutila, associate professor of industrial engineering, College of Engineering, Syracuse University, for the rich insights gained from him about operations research, dynamic programming, game theory and decision theory. His guidance in helping to solve mathematical problems was invaluable.

Any errors, weaknesses or limitations found in this report, however, are the sole responsibility of the author. Any contribution which this study makes toward the development of a more adequate model of communication-decision behavior, the author will owe to the assistance and support he has received from Dr. Holder and to the discussions had with Professor Jutila.

Specifically, the focus of attention is being directed at the phenomena of how adolescents make decisions to continue or discontinue their education beyond high school.

Information (or, more accurately the lack of information) about the phenomena of how colleges and universities are selected by aspiring applicants stands in sharp contrast with the available information about how these institutions of higher education choose their students.

Even admitting that the actual process of college admission is a complex (and not infrequently a mysterious) process to the applicant as well as to who are advising the applicant, nonetheless there are more objective data available and accessible about college admission policy and procedures than there are about the college-going behavior of thousands of applicants who each year are required to make a host of critical decisions about their qualifications as a candidate, about what college they should select, and about what they should do academically once they get into college.

Even researchers who have done the most work in investigating this area are the first to admit that we have little systematic information about the decision to go to college.

Hence, there is a host of questions for which answers are in short supply: What factors enlarge or narrow a youngster's opportunity to choose to go to college? How does an adolescent develop a college orientation? What are the psychological factors which encourage and motivate a youngster to want a college education? What sources of information and influence, in addition to parents and peers, are important in choosing college? In short, one of the critical problems is that of finding out more about the processes by which particular colleges and universities are chosen, and understanding more about what and who is likely to influence this choice.

In coming to grips with this kind of problem, one faces the temptation to interpret what research data we have about the transition from secondary school to college in ways which overgeneralize the student's college-going behavior, and which, in turn, lead to inconsistent and conflicting conclusions.

Since the high school youngster is an adolescent, it is easy to view him as a passive agent whose behavior is shaped and directed by others who are the real decision-maker in the college-choice situation. These can lead to excessive "sociologizing" in the explanation of college selection.

The factor of "social influence" is frequently explained in terms of the observation that people in close contact for long periods of time (such as in the cases of parents and children, student and members of his peer group) are found to have remarkably nonindependent preferences.

Havighurst,[2] for example, has shown the influence of peer group values in determining whether lower-class youths decide to go to college. The study made by Kahl[3] shows that in the lower middle class families, parents translated their personal dissatisfaction into a mobility quest as they communicated it to their sons. Hill[4] concluded in his study that the most potent determinants of college proneness are in the cultural and educational traditions, ambitions and hopes of the family; in short, a history of college attendance in the family, friends in college or going, identification of college education as a means of improving one's lot--all are strong determiners of proneness.

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[2] R. J. Havighurst and R. R. Rogers, "The Role of Motivation in Attendance at Post-High School Educational Institutions," _Who Should Go to College?_, ed. by B. S. Hollinshead (New York: McGraw-Hill Book Co., 1957), pp. 135-65.

[3] J. A. Kahl, "Educational and Occupational Aspirations of 'Common Man' Boys," _Harvard Education Review_, XXIII (1953), 186-203.

[4] G. E. Hill, "College Proneness, A Guidance Problem," _Personal Guidance Journal_, XXXIII (1954), 70-73.

What these studies demonstrate is the high correlation among the preferences and choices displayed by members of family and peer groups. As has been pointed out elsewhere,[5] however, the objectionable "sociologizing" of this phenomenon comes about when attempts are made to interpret how these correlations come about. It is tempting to make the college choice itself a function of deliberate social manipulation by others or conscious adaptation of a passive agent to the behavior of others.

Admittedly no one seriously advocates this kind of "social determinism" when pressed; and nearly everyone seems eager to admit the necessity, if not the primacy, of at least two other determinants of choice behavior: 1) the type of environmental stimuli which a person can select to respond, i.e., selective perception, and 2) the internal psychological disposition which persons bring to his environmental situation.

Focusing on a person's need-disposition, however, can lead to another kind of oversimplification, namely, nonrational, impulsive behavior. This conclusion is easy to reach given the kind of complexity a high school student faces in his efforts to select a college.

Rational and realistic decision-making about college presupposes that one has some information and knowledge about various alternatives, or must know how to get the necessary information. But many who provide formal or informal guidance--parents, peer group members, relatives--frequently lack this sophistication. This is particularly true among lower class and uneducated parents. Even a trained high school guidance counselor has his problems in this respect; it is doubtful whether any guidance counselor can provide expert advice about every one of the 2,000-odd colleges and universities in the United States.

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[5] William N. McPhee, Formal Theories of Mass Behavior (New York: The Free Press of Glencoe, 1963), pp. 74-75.

It has also been pointed out[6] that the decision to go to college is often based on vague impressions of college reputations rather than on a more refined knowledge of colleges and their offerings. Things are further complicated for the college candidate by the fact that as higher educational institutions absorb a larger and larger proportion of the adolescent population the range of talents and interests to which these institutions cater increase; as a result the college curricula develop more and more specialized programs. This situation only tends to heighten the potential applicant's uncertainty about what sequence of courses he ought to take in college, what program of study he should pursue, or in what particular division he should enroll.

Finally, the process of choosing a college ideally assumes that a decision should be determined in terms of the special talents and needs of the individual candidate. This ideal, however, raises the question as to whether high school youngsters are given the information, or, if the information is given, have the capability, to make a realistic assessment of their own talents or their own emotional needs.

Portrayed in this light, the student's situation contains a vast amount of uncertainty about the reliability of his information sources, about available alternatives, and about his own talents and needs. Hence, one is almost led to believe that the choice of a college is the result of some kind of blind behavior--a choice which is based on chance selection or on nonrational impulses.

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[6] Elizabeth Douvan and Carol Kaye, "Motivational Factors in College Entrance," The American College, ed. Nevitt Sanford (New York: John Wiley & Sons, 1962), pp. 199-224.

One aspect of the problem which emerges from current educational research relates to the inconsistencies which frequently are found in the actions and statements of education policy-makers and in the literature on guidance theory. Efforts to find determinants which will explain how students choose colleges tend to lead simultaneously to two opposing conclusions: 1) that influence factors which determine decision-making about college can be explained in terms of "social determinism" whereby the student's college-going behavior is almost wholly determined by external factors (e.g., social class, economic status, geographic distance) or other influentials (e.g., parents, peer group, teachers, guidance counselors and the like), or 2) that the college choice is a function of motivational, and hence, nonrational, factors giving rise to a kind of "psychological determinism" whereby the student's college choice behavior is almost wholly determined by a set of internal and hidden drives, needs, and impulses.

The other aspect of the problem may be stated as follows: If, indeed, a high degree of determinism were present and operating in the high school-to-college transition system, then one would suspect that the ability to predict student choice behavior ought to be of a high order. Yet, current educational research tells us otherwise. As Sanford[7] has observed, one overriding observation stands out in recent studies of students entering college: diversity is the prevailing factor.

We find diversity or variety among colleges and diversity among students entering the same institution. We find variety--and ever increasing amounts of variety as the total college population expands--in student abilities, in student personality, and in student social characteristics.

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[7] Nevitt Sanford, "Higher Education as a Field of Study," The American College, ed. Nevitt Sanford (New York: John Wiley & Sons, 1962), pp. 31-73.

Such diversity and variety obviously emphasize the variability operating in the system; hence, the greater the amount of deviation from normal expectations, the more difficulty one encounters in making any meaningful and significant predictions about the student's college-choice behavior.

It has been noted[8] that the roles played by the more allusive and subtle motivational variables in college decision-making produce surprises and create slippage in the predictions which are based strictly on more accessible and objective factors such as intelligence, social class, economic status, and the like.

Such "slippage" is found in predicting who decides to go or not to go to college, who will select which college, and, once in college, who drops out or transfers to another college.

Several researchers have observed that the high drop-out and transfer rates indicate something goes wrong in the college-choice process. While they have recommended more careful counseling of students at the time of the initial decision, they have also noted that there is a need for more accurate information on all aspects of "this fateful process of deciding."

Douvan and Kaye summarized the problem in this fashion:

> The dropout and exchange rates in American colleges suggest that something goes seriously awry in this choice process. Even discounting the large number of transfers that occur because of the move from junior college, the rates seem to reveal a widespread choice based on inappropriate or transitory needs. The shopping around that occurs _after_ the adolescent is already in college must cause him a great deal of loss and unhappiness. One suspects, at least, that some of the grief might be prevented by more careful counseling of students at the time of the initial decision. One readily researchable

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[8] Douvan and Kaye, _op_. _cit_., p. 199.

> question in this area is simply how stable (i.e., nontransferring) student and those who shift about differ in regard to the original selection of schools--in the use of various criteria, advisors, and so forth. An investigation of this kind could be done in a relatively short-term longitudinal research, or, at least for exploratory purposes, in a retrospective design. One thing is certain: we are badly in need of more accurate information on all aspects of this fateful process of deciding.[9]

If this can be assumed to be a reasonable statement of the problem, then it becomes the objective of study presented herein to focus on several aspects of this problem and suggest ways which may be used in carrying out more detailed analysis of student communication-decision behavior in the transition from high school to college.

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[9] *Ibid.*, p. 223.

II.

COMMUNICATION-DECISION BEHAVIOR AMONG HIGH SCHOOL STUDENTS: EMPIRICAL SETTING OF THE CURRENT SIMULATION STUDY

The study presented in this report grew out of an empirical study, similar in type to the one recommended by Douvan and Kaye. It was designed to focus on the communication and decisional attributes made manifest in the student's search for college-related information, in the student's communication contact with various information sources, and in the student's uncertainty and concern about various kinds of questions which he had about his capability of going to college and the college environment.

This communication-decision research effort (the so-called CODE Project) was begun in 1962. A College Information-Decision (CID) Questionnaire has been administered annually to incoming freshmen students at Syracuse University by the Communications Research Center. The questionnaire is administered during "Orientation Week" in September immediately preceding the opening of the University and as part of the battery of assessment tests conducted during this period.

A 300-item questionnaire was administered to incoming freshmen students in the fall of 1962, 1963, and 1964. A revised version, a 126-item questionnaire, was administered to incoming freshmen in the fall of 1965 at Syracuse University and Baylor University.

A comparative analysis was made of the 1962 and 1963 data, and the findings and conclusions of this study led to the request for funds from the Office of Education to undertake a new study,

the results of which are set forth in this report.

The Syracuse Communication-Decision (or CODE) Project, therefore, is divided into two parts. The older (and Syracuse University supported) part is a project which conducts empirical studies of communication-decision behavior (EMCODE) and, hence, is concerned with the continuous analysis of empirical data yielded by the CID Questionnaire administered each fall to incoming freshmen.

The second part is the SIMCODE Project which is concerned with designing a simulation model of communication-decision behavior for computer manipulation. This part of the CODE Project is supported by the OE-6-10-008 contract with the U.S. Office of Education. The objectives of the SIMCODE Project are 1) to develop a workable and empirically grounded theory of communication and decision-making relative to high school students continuing or discontinuing their education; 2) to design a formal model, using the Markov chain process, to characterize this communication-decision theory; and 3) to experimentally test this model by computer manipulation.

The SIMCODE Project is dependent upon the EMCODE Project in two ways. First, the empirical analysis of student information-gathering and decision-making behavior yielded relationships among attributes which a workable theory of communication-decision behavior needs to take into account in order to make it meaningful and relevant. Second, EMCODE provided data which could be employed to make estimates of parameters to be used in the mathematical model when computer manipulated.

The heart of a simulation program is, of course, the mathematical model which one intends to employ in computer operations. Hence, the critical problem to which the SIMCODE Project was directed concerned the possibility of developing a representation of actual decision-making as it occurs over time. Such a model, therefore, has to function dynamically.

In the field of applied mathematics one can find a number of mathematical models[10] which have some, but not all, of the properties to simulate the actual characteristics of dynamic decision-making displayed by high school students relative to higher education. Such a model had to be designed.

During the first half of the contract period (i.e., July 1, 1965, to September 30, 1965), the major effort was directed at the development of a usable communication-decision theory and the construction of a mathematical model which permitted the manipulation of transitional probabilities over time. Such a model was developed.

The final phase of the project was completed during the last half of the contract period (i.e., October 1, 1965, to January 31, 1966). This final step relates to computer programming, analysis, and testing (i.e., the COMPAT Phase of the SIMCODE Project). This phase entailed writing the computer program for the simulation project, analyzing the program logic (and making adjustments and modifications), and testing the model experimentally on the computer. This phase of the project also has been completed, and runs have been made to obtain simulated results of communication-decision behavior. These results have been matched against the

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[10] T. W. Anderson, "Probability Models for Analyzing Time Changes in Attitudes," Mathematical Thinking in the Social Sciences, ed. Paul F. Lazarsfeld (2d ed. rev.; Glencoe, Ill.: The Free Press, 1955), pp. 17-66; Jean E. Draper and Harry H. Nolin, "A Markov Chain Analysis of Brand Preference," Journal of Advertising Research, IV, No. 3 (1964), 33-38; I. Blumen, M. Kogan and P. J. McCarty, The Industrial Mobility of Labor as a Probability Process (Ithaca, N.Y.: Cornell University Press, 1955); H. G. Landau, "The Distribution of Completion Times for Random Communication in Task-Oriented Groups," Bulletin of Mathematical Biophysics, XVI (1954), 187-201; R. R. Bush and F. Mosteller, Stochastic Models of Learning (New York: John Wiley & Sons, 1955); McPhee, op. cit.

EMCODE data to determine the closeness of fit.

We turn now to the EMCODE findings against which the simulated model is being compared. The EMCODE Project focused attention on several attributes of communication-decision behavior: 1) how high school students obtained information about college, 2) from what sources students obtained information about what kind of college-related topics, and 3) the interplay between this communication behavior and the decision to attend college. Sources of information included both personal (i.e., other individuals) and impersonal (i.e., mass media); the aim of this research was to investigate the communication-decision behavior of students in their relations with personal and impersonal media.

An analysis of the responses of just over 4,000 incoming Syracuse University freshmen to the College Information-Decision Questionnaire led to the following empirically-supported observations:

1. The high school student is truly a decision-maker. As alluded to above, hypotheses have been advanced by educational researchers suggesting that the high school younster is by and large a passive agent whose college-going behavior is influenced by others, primarily adults (e.g., parents, relatives, professional educators) and to some extent members of his peer group, that the student does not have access to adequate information to make a realistic choice of a college, and that he lacks the maturity and sophistication to make a wise assessment of his own intellectual talents or his emotional needs. From this one would almost conclude that high school students do not engage in rational decision-making, that his college-going behavior is largely determined by external social forces (i.e., other influentials who inject whatever rationality there is to be found in the college-going system), and that, where guidance of rational decision-makers is lacking, the student makes essentially nonrational choices based on vague

impressions and impulsive emotional needs.

All this may be admitted as being partly true; However, it is necessary to distinguish between 1) the outcomes relative to a student going to college desired by an adult (say, a professional educator) and the outcomes desired by a youngster who is thinking about college, and between 2) the criterion (or criteria) employed by an adult in optimizing these outcomes and those employed by a high school teen-ager. It does not follow that because the adolescent seeks outcomes and employs selection criteria which differ from adults that somehow the youngster does not engage in rational decision-making or that he does not seek to optimize. These distinctions are critical. To ignore them is to falsely assume that there is only one ideal decision-making model and that such a model yields only one, unique solution. This whole question is more fully investigated below.

Suffice it to say here that the empirical evidence yielded by EMCODE showed rather clearly that high school youngster engages in rather complex and sophisticated decision-making relative to 1) sampling his information-yielding environment, 2) choosing information sources, 3) evaluating these sources in terms of the reliability of the information, and 4) distinguishing between and among sources according to a number of communication criteria.

Further, students also displayed considerable independence in making decisions about college-going. Less than 5 per cent (4.6) indicated that the decision to go to college was made by their parents, while approximately 48 per cent (47.66) of the students indicated that their college choice was made independently or in opposition to their parents' wishes.

Finally, the empirical evidence indicates that the student exercises considerable control over his own communication state and over his communication environment relative to decision-making about college. He operates in a purposeful state(as this term is technically defined in communication theory) giving both form and direction to the communication net in which he participates. Hence, we can say that the student decision-maker engages in behavior in which he makes real choices--that is, his information-seeking behavior is not a random process nor is it completely dominated by his environment.

2. The kind of information the student seeks is related to the amount and type of uncertainty (as technically defined in information theory) he has about attending college and the kind and amount of communication (as technically defined in communication theory) he receives is related to the state of his indeterminism and to his decision-making process. Empirical data have provided us with a clearer picture of the interplay between external constraints (i.e., environment factors) and internal states (i.e., psychological orientations and dispositions). Clearly there is no reason to assume that one of these dominates the other. It is more reasonable to assume that the two interact in such a way as to make the high school student an active (rather than a passive) agent in the college-going system.

3. The size of the communication net in which the student participates is relatively large as compared to other sub-groups. Earlier studies conducted by Lazarsfeld and his associates[11] suggested the size of the group of "opinion leaders" or "influentials" to be small. However, the results of the EMCODE studies do not support such a conclusion with reference to college-bound high school students. The students' communication net contains a number of contact points. The net is not limited to the immediate family and a few close friends. The student in his search behavior

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[11] E. Katz, "The Diffusion of New Ideas and Practice," The Science of Human Communication, ed. W. Schramm (New York: Basic Books, Inc., 1963), pp. 77-93; E. Katz and P. F. Lazarsfeld, Personal Influence (Glencoe, Ill.: The Free Press, 1955).

ranges well outside this narrow circle. The communication net contained on the average about ten members.

4. Each information source utilized by the student tended to be assigned a specialized communication role. In other words, each member of the communication net possesses a unique communication role in terms of the subject-matter emphasis and information provided. This finding agrees with previous research findings, which suggested that opinion leaders are specialists and that those people who provide information on one subject might not be consulted for information on other subjects. Such is the case with the student. Some interpersonal sources were found to emphasize particular facets of a college education while others emphasized other facets.

5. The student who attends college functions in a social and communication environment which strongly reinforces his decision to attend college. This finding also agrees with the conclusions arrived at by other researchers who have shown that a high positive correlation exists between a student's college proneness and the favorable orientation toward college displayed by parents and peers. Here we are faced with the problem alluded to earlier, namely, how to define the role and assess the effect or impact of the "external" social environment on the student's college-going behavior. The question which emerges at this point is whether the student is passively assimilated into a college-oriented social group (either by accident such as being born into it or deliberately such as being recruited), and, once in this group, whether the student's college-going attitudes and behavior are largely manipulated and shaped by the various "influentials" within this group.

Of course, the more reasonable assumption is that there is an interplay between factors in the social environment and factors in student's psychological orientation; but this assumption is also the most difficult to demonstrate empirically. Data from the EMCODE study at least suggest tentatively that this assumption holds. The EMCODE data showed that slightly over 75 per cent (75.19) of the students entering college had manifested a high interest in or an attraction for college before they entered high school, suggesting, at least, that those students who get into college have a history of early involvement in the college-going system. Interestingly, there is also association between early involvement and high communication activity (this relationship had a chi-square of 39.269, significant at p. = .01 and the degrees of freedom = 12). In other words, those students who started thinking about college early display a high exposure index and are more involved in information-exchange behavior than those who began thinking about college later. This suggests that early involvement may generate high amount of communication activity through which the student decides whether he will remain in or get out of the college-going system. This result also suggests that the communication net in which the student participates is not ready-made nor fixed; rather it may be argued that the student in fact creates this communication net in the way he makes decisions about which information source he will contact relative to the several college-related topics.

In other words, given an environment, the student has open to him several options, namely, whether to associate with persons with a pro-college orientation, or with persons with anti-college orientation, or with those with a neutral or ambivalent college orientation. Since he has some freedom in this selection, he also has some control over the communication variables found in his environment.

The final point is that this communication-decision process is ongoing, and, hence, developing over time. To understand, then, how a student arrives at a point of commitment (the point where he makes terminal decisions and engages in some overt behavior relative to college going), it is necessary to study this college-going or high school-to-college transition process over time.

Hence, the EMCODE longitudinal study has succeeded in yielding two kinds of results, thereby, setting the framework for the SIMCODE Project. First, the EMCODE data produced empirically grounded conclusions about student behavior around which a more generalized communication-decision theory could be built. Second, it pointed up the limitations of conventional statistical analysis in developing both a more viable theory and a model of communication-decision behavior.

Conventional statistical analysis requires the adoption of a stationary (or static) probabilistic model to represent the reality one is attempting to analyze. In other words, this approach requires one to treat the reality of communication-decision system as if it behaved as a stationary system. The assumption one has to make is that certain critical communication-decision attributes are normally distributed over time, permitting one to hold time as fixed.

At the same time, descriptive statistical analysis also requires one to simplify the reality under analysis in such a way that it can be managed and studied. Hence, one builds a conceptual scheme in such a way that certain variables can be isolated and the degree of association between and among these variables can be specified and tested. All other variables falling outside of the conceptual scheme or model are held as fixed or assumed to be constant.

Traditionally, if one is interested in so-called "external" or sociological variables, one holds psychological variables as fixed; and if one is interested in the behavior of "internal" or psychological variables, one holds certain sociological variables as fixed. While these approaches in studying human behavior are both legitimate and sensible, the results which these approaches yield are interpreted frequently in such a way (particularly by educational policy-makers who tend to seek simple cause-and-effect answers) as to give rise to the objectionable "sociologizing" referred to earlier.

Hence, there is a need to construct models of communication-decision behavior which can overcome, at least theoretically, these defects.

This report describes one such communication-decision model which has the desired subtlety to do the following:

1. Takes into account both external and internal factors, that is, to leave the determination of college choice to both a) the external stimuli (information obtained through communication with other information sources) and b) the internal states (the individual's psychological or motivational disposition).

2. Takes into account time-dependency, namely that communication-decision behavior function over time, or dynamically. In other words, communication and decision-making are assumed to move along a continuum bounded at one end by indeterminism (indecision) and at the other end by determinism (decision) over time.

III.

COMMUNICATION-DECISION BEHAVIOR: A CONCEPTUAL FRAMEWORK AND DEFINITION OF TERMS

The purpose of the SIMCODE study is to conduct an exploratory investigation into ways of analyzing the amount of involvement (or disinvolvement) on the part of various groups of high school students in the college-oriented systems in which they participate through communications.

Simply stated, we can say that a student is highly involved in a college-oriented system if he has a strong commitment to go to college; his involvement is low, if he has a weak commitment to go to college.

To clarify the critical terms employed in the above statement, the following definitions are offered:

By "various groups" of high school students is meant either natural or categorical groups or both, where groups may be defined variously in terms of a set of family income categories, set of scholastic achievement categories by class rankings or location in the distribution on standardized aptitude scores, a set of social categories such as family, kinship, friendship, ethnic, and the like.

By "college-oriented system" is meant that social organization which designates a collectivity of actors which has the general commitment of preparing and inducing high school youngsters to enter institutions of higher education; such as a collectivity would include, among others, parents, teachers, peer groups, school administrators, education policy-makers, officials and faculty members of colleges and universities, employers seeking college graduates, and the like.

By "participation in the college-oriented system" is meant the communication-decision activity in which a youngster must be engaged by virtue of his role as a high school student. In the social system in which the adolescent fulfills his role as high school student, he is confronted with sets of alternatives or various courses of action which determine whether he will continue or discontinue his high school education, with the choices of planning to go to college, with the options of whether he will or will not go to this or that particular college, and so on.

In this context, we can talk about the student's activities as purposeful behavior of an individual.[12] An individual may be said to be in a purposeful state if he has alternative courses of action available to him--courses of action which have some, but unequal, efficiency for obtaining a desired outcome. The components of a purposeful state, therefore, are 1) the individual, 2) the available courses of action, 3) the possible outcomes, and 4) the environment.

The college-oriented system is that system in which the purposeful college-going behavior can take place with reference to alternative courses of action which determine whether the individual remains in the system. In such a system, then, we can identify two basic processes or subsystems: 1) the process of communication and 2) the process of involvement.

Communication is defined as the process by which, with the use of messages, one purposeful individual can influence the purposeful behavior of another. By the amount of communication is meant the proportion of change in influence; and influence, in turn, can be described in terms of intensity and direction. Intensity ranges between high and low; the direction is either positive or negative.

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[12] See footnote 13.

Involvement is defined as the process by which, through ascriptive activity in which cathectic interest and appreciative standards have primacy, an individual relates himself to social objects in terms of wanting and liking.

By the amount of involvement is meant the proportion of change in orientation. Orientation may be described in terms of intensity and direction. Intensity ranges between high and low; direction is either positive or negative.

We refer to positive involvement as commitment and to negative involvement as alienation. Individuals, therefore, may be located on an involvement continuum which ranges from a highly intense negative area through mild negative and mild positive areas to a highly positive areas.

We now wish to look more closely at the interrelationship of involvement and communication.

We know that the press of the socio-cultural environment on the individual is important. Small group, sociometric, and personal influence studies have shown that people in close contact in so-called friendship groups have remarkably nonindependent preferences (i.e., they share like preference and make similar choices). Hence, if a high school student is exposed to a social group which has as its value patterns a set of norms that make a college education a highly desirable goal, we would expect that student to have a similar preference; conversely, if a student is exposed to a group whose norms assign a much lower value to college education (say, in a negative, alienative, or hostile way), we would expect that student to orient to college education in a negative manner.

However, we also know that not every student exposed to a positively college oriented group wants to go to college, or, in fact, goes to college; and by the same token, not every student in a negatively college-oriented group chooses not to go to college.

Group norms and group pressures are admittedly important, but they do not operate wholly independently of the individual's psychological set--that is, the motivational factors which may be defined in terms of orientation modalities (cognitive, cathectic, evaluative modes of psychological behavior). Hence, internal, psychological dispositions of the individual student must be taken into account as variables which affect the direction and intensity of the individual orientation to social objects.

What we have here is essentially a conflict situation (varying in degree of intensity over time) between the externally perceived group pressures and the individual's internal state of need-gratification.

The need to reduce cognitive uncertainty and/or cathectic tension places the individual in a search state. Such a search state operates in a communication-influence context in which the individual interacts with another in an information-seeking, decision-making way. In this process, decisions are arrived at by either "objective-reality testing" or "social-reality testing" (as these testing processes are defined by the late Kurt Lewin and his associates).

This externally perceived communication-influence and internally responding information-decisional process may be studied in an operational way by viewing this process as a behavior system in which one purposeful individual affects the purposeful behavior of another.

The value of an individual purposeful state,[13] in turn, may be viewed as a function of three measures which can be expressed in precise quantitative terms. These measures are derived from the three modes of communication: 1) a message that changes an individual's probabilities of choice (such a message informs or misinforms an individual), 2) a message that changes the efficiencies of the courses of action (such a message instructs or misinstructs the individual), and 3) a message that changes the values or utilities that the individual places on outcomes (such a message motivates or demotivates an individual). Studies of social communicative behavior, approached from this particular operational point of view, have been carried out and made to yield meaningful quantitative results.

This approach yields one way of defining and measuring the amount of communication. In other words, we can say that an individual A_1 communicates with another individual A_2 if a message produced by A_1 changes the characteristics of A_2's purposeful state--that is, produces a change in A_2's state variables. These variables are defined as follows:

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[13] What is presented in this paragraph and the one following is a verbal description of a mathematical theory of communication initially set forth by Russell L. Ackoff in his writings. See R. L. Ackoff, "Towards a Behavioral Theory of Communication," Management Science, IV (1958), 218-34; R. L. Ackoff, Scientific Method (New York: John Wiley & Sons, 1962), pp. 164-70; R. L. Ackoff, "The Development and Nature of Operations Research and its Relevance to Educational-Media Research," presented at the conference on "New Dimensions for Research in Educational Media Implied by the 'Systems' Approach to Instruction," conducted by the Center of Instructional Communications of Syracuse University, April 2-4, 1964; R. L. Ackoff, "Systems, Organization, and Interdisciplinary Research," General Systems Yearbook, V (1960), 1-8; Martin, one of Ackoff's associates, has applied this theory in a study of scientific literature. See Miles W. Martin, Jr., "The Measurement of Value of Scientific Information," Operations Research in Research and Development, ed. Burton V. Dean (New York: John Wiley & Sons, 1963), pp. 97-123. This theory will be treated at some length in the sections below.

P_i : the probability that A will select a certain course of action C_i.

E_{ij}: the probability that a course of action C_i will yield the outcome O_j.

V_j: the relative value of the jth outcome to A.

In other words, communication is being defined in terms of what it does to the internal or purposeful state of an individual. If none of the state variables is changed, no communication has taken place.

A second way of defining and measuring communication is to observe how an individual interacts with his environment--that is, to see what changes are produced in A's environmental or external states. Here we take into account the number of message sources with which an individual interacts communicatively and the number of message items about which the individual communicates.

The joint occurrence of message sources and message items yield a matrix of the amount of contiguity or exposure. In other words, communication is here being defined in terms of what it does to the external or interactional state in which an individual participates.[14]

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[14] This is the more traditional way of defining and measuring "communication," and widely used in most sociological studies of communication, diffusion, and innovations, in studies of the effect of mass communications, in advertising research, and mass media analysis. For a review of research employing this measure see David K. Berlo, The Process of Communication (New York: Holt, Rinehart and Winston, Inc., 1960; Wilbur Schramm (ed.), The Science of Human Communication (New York: Basic Books, Inc., 1963); Joseph T. Klapper, The Effects of Mass Communication (Glencoe, Ill.: The Free Press, 1960); Everett M. Rogers, Diffusion of Innovations (New York: The Free Press of Glencoe, 1962); D. B. Lucas and S. H. Britt, Measuring Advertising Effectiveness (New York: McGraw-Hill Book Co., 1963). A somewhat different approach to the measure of mass communication is found in M. L. De Fleur and O. N. Larsen, The Flow of Information (New York: Harper & Bros., 1958).

Similarly, there are two ways of looking at information.

A message may be said to contain information to the extent that it alters the amount of information initially found in the purposeful state of the individual so that the individual's probability in selecting a course of action is changed. If an individual is in a state of indeterminism (in which the alternative courses of action are equally probable and, hence, provides no basis for choice) and a message alters this state in such a way that the state is moved on a scale toward determinism (where he has complete basis for choice), then that message has increased the individual's probability to make a choice--and, hence, has informed him.[15]

A message may also be said to contain information to the extent that it reduces uncertainty. Given a set of possible categories to which an object may be assigned, then the amount of uncertainty at the receiving end before a message is received is the a priori probabilities of message assigning an object to any of the possible categories. Hence, the amount of information contained in the message is equal to the amount of uncertainty that the message will reduce when it is received.[16]

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[15] See Ackoff, op. cit.; and Martin, op. cit.

[16] Extensive treatment of the mathematical concepts and application of information theory can be found in C. E. Shannon and W. Weaver, The Mathematical Theory of Communication (Urbana: The University of Illinois Press, 1949); Robert M. Fano, Transmission of Information (New York: John Wiley & Sons, 1961); Gordon Raisbeck, Information Theory (Cambridge, Mass.: The M.I.T. Press, 1964); Stanford Goldman, Information Theory (New York: Prentice-Hall, Inc., 1953); F. M. Reza, An Introduction to Information Theory (New York: McGraw-Hill Book Co., 1961).

IV.

FIRST STEP IN DESIGNING A COMMUNICATION-DECISION MODEL: CHOICE OF "OPTIMAL" STRATEGY IN RELATIONS TO THE STATE OF INFORMATION[17]

Given the above conceptual framework, the question now is whether a formal model of a communication-decision process can be constructed which can represent the behavior of high school students in making choices about a college education. We can take as our starting point the decision process itself.[18]

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[17] For the mode of presenting decision theory in this section the author is indebted to Professor Jutila. See footnote 1.

[18] The literature on decision-making is extensive. See, for example, R. Duncan Luce and Howard Raiffa, Games and Decisions (New York: John Wiley & Sons, 1957); Herman Chernoff and Lincoln E. Moses, Elementary Decision Theory (New York: John Wiley & Sons, 1959); Ewald Burger, Introduction to the Theory of Games (Englewood Cliffs, N. J.: Prentice-Hall, 1963); Melvin Dresher, Games of Strategy: Theory and Application (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1961); David W. Miller and Martin K. Starr, Executive Decision and Operations Research (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960); Henri Theil et al., Operations Research and Quantitative Economics (New York: McGraw-Hill Book Co., 1965); C. West Chruchman et al., Introduction to Operations Research (New York: John Wiley & Sons, 1957); William J. Baumol, Economic Theory and Operations Analysis (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1961); Arnold Kaufmann, Methods and Models of Operations Research (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963); Walerian Kipiniak, Dynamic Optimization and Control (New York: The M.I.T. Press, and John Wiley & Sons, 1961); Maurice Sasieni et al., Operations Research (New York: John Wiley & Sons, 1959).

The formal decision model can be built up as follows:

It can be assumed that an adolescent, as he moves through the educational system from elementary to secondary level, has learned something about the educational system beyond high school called college education. Within his experience, and using in addition his imagination and reason, he is able to relate himself to a college education in terms of his capabilities. Further, he is able to formulate a relatively simple decision model which he is able to employ to predict and control his behavior for the goals he is forming over time.

Among other things, the adolescent seeks to know what state he is in relative to his capabilities of going to college at any given time. Hence, the adolescent's decision model may be described as follows:

1. The adolescent has learned over the years (say, during his years in elementary school) that he has open to him several alternative courses of action relative to going to college. Intuitively, he confines his alternative courses of action to two basic ones. These constitute his alternative state.

a_1: Do nothing out of the ordinary about getting into college--that is, continue doing what he has done in the past and simply assume that everything will turn out to his satisfaction. Planning for college would be done at low cost, requiring nothing extra in time and effort, and therefore, the actual college selection will be left until his senior year in high school.

a_2: Make a special effort to get into college. Such action would require that planning for college would have to be started early in high school and a lot of time and effort would have to be expended to make sure that he meets all the college-going requirements (e.g., academic, aptitude, financial, and the like).

2. Further, the adolescent believes that it is sufficient to portray his college-going potential by two distinct states

of affairs:

Q_1: His college-going capabilities are good--that is, his personality, interests, and scholastic performance are favorably ranked in terms of college-going by various people who exercise some influence or control over his going to college. These people include his teachers who grade his school work, his parents who have to pay college tuition, and so on.

Q_2: His college-going capabilities are poor--that is, his personality, interest, and scholastic performance are not ranked favorably (or ranked unfavorably) in terms of college-going by those people who exercise influence and control. Hence, in this state his chances of going to college would be low.

3. The adolescent, with his experience in the educational system at the elementary level, has been able to associate a utility value with a particular course of action taken under a specific state of affairs. This set of values constitutes his utility state.

Hence, the adolescent is able to devise a utility loss table which could possibly take the following form:

Utility Loss = $L(Q,a)$

	a_1	a_2
Q_1	$L(Q_1, a_1) = 0$	$L(Q_1, a_2) = 2$
Q_2	$L(Q_2, a_1) = 7$	$L(Q_2, a_2) = 3$

This means that: 1) the adolescent feels that he would suffer no loss if he did not have to make any special effort and still was able to get admitted into college, $L(Q_1, a_1) = 0$; 2) he feels that he would suffer some loss if he elected alternative a_2 and had to make a special effort to improve his capabilities for getting into college, $L(Q_1,a_2) = 2$; 3) he feels that he would suffer considerable loss if he made no special effort and, as a result, would find himself unable to go to college--a situation which might have been avoided had he made a special effort, $L(Q_2,a_1) = 7$; and 4) he feels he would suffer some loss if he made a special effort only to find that he still lacked college-going capabilities, but at least he would feel that he had done his best, $L(Q_2,a_2) = 3$.[19]

This is one way of looking at the consequence. He has an alternate way open to him. Instead of thinking about *utility loss*, he can think in terms of *regret*. He may realize that in state Q_2 he is bound to take a minimum of loss of $L(Q_2,a_2) = 3$ in any case. Therefore, it may be better to consider only regret, that is the incremental utility losses beyond whatever losses one is bound to take in a given state of affairs. Hence, the adolescent might think in terms of the following regret table:

Regret = $R(Q,a)$

	a_1	a_2
Q_1	$R(Q_1,a_1) = 0$	$R(Q_1,a_2) = 2$
Q	$R(Q_2,a_1) = 4$	$R(Q_2,a_2) = 0$

There are, of course, many other ways that the adolescent could define his alternatives, his state of affairs, and his utility values.[20] For example, he could define his alternatives in terms of a_1 = electing not to go to college and a_2 = electing to go to college, and his state of affairs in terms of Q_1 = having high college-going capabilities, Q_2 = average college-going capabilities, and Q_3 = low college-going capabilities. And he could associate various kinds of utility values relative to the joint occurrences of his alternate courses of action and his state of affairs.

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[19] The values of the utility loss are rough estimates derived from empirical data provided by students in personal interviews using the Ackoff's "Case method of relative value." See R. L. Ackoff, *Scientific Method*, pp. 87-97.

A communication model which deals with the problem of alternative selection, outcome selection, and assigning values or utilities to outcomes will be treated in more detail below.

4. Finally, the adolescent, it may be assumed, realizes that he needs certain kinds of information to estimate and detect what state of affairs he is in or what state of affair is most likely to prevail in the immediate future. For example, he can obtain information by engaging in various kinds of communication activity such as talking with his parents, high school friends, high school guidance counselor, and the like; and, at the same time, he can obtain information about college from the mass media, college catalogs, other college-related literature, and so on. Within the experience gained through this kind of communication

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[1] It should be noted here that there is no one, single, or unique decision model. Decision models are built by individuals. As Jutila, _op_. _cit_., observed, constructing a decision model is like artist painting a landscape. One could ask several artists to go out and paint the same landscape in a way so it could be recognized. No two artists would paint identical pictures; nor would one artist paint the same landscape in an identical manner. The question here is not complete identity, but one of permitting the viewer (in this case) to "recognize" the landscape which has been painted. The same holds for decision models; one wishes to develop a model which _represents_ a particular kind of process, not one which is an exact _duplicate_ of the process.

activity (e.g., numerous conversations, discussions, interviews, exposure to mass media), the adolescent, it may be assumed, is able to classify his information-yielding observations relative to the two states Q_1 and Q_2 into the following categories:

z_1: Information (obtained from various sources) favoring or encouraging the adolescent to go to college.

z_2: Information obtained from sources which do not favor or encourage him to go to college.

The adolescent, of course, could classify information in a more elaborate manner, yielding several information states. But here we will assume that this two-category state is sufficient for the adolescent in making decisions.

Now, the adolescent can study the history of these kinds of observations relative to the two possible states of affairs. He can review his own personal history to find out how frequently a particular information state was associated with a particular state of affairs or he can examine this type of association relative to other high school students or friends. Suppose that as a matter of history, he found that observations yielding information z_1 and z_2 about his state and the state of other students yielded the following frequency table:[21]

	z_1	z_2
Q_1	$f(z_1 \mid Q_1) = 0.8$	$f(z_2 \mid Q_1) = 0.2$
Q_2	$f(z_1 \mid Q_2) = 0.1$	$f(z_2 \mid Q_2) = 0.9$

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[21] These values were estimated from the frequency distribution yielded by the students' responses to the College Information-Decision (CID) Questionnaire relative to personal sources supporting (and not supporting) the student's college choice.

The values in the cells are conditional probabilities, that is, the value is the frequency of z_i occurring given the state Q_j, i.e., $f(z_i|Q_j)$. This table means, therefore, that when a student was observed to be in a state where his capabilities of going to college were good, 80 per cent of the information sources communicated z_1-like information and 20 per cent of the people communicated z_2-like information. Similarly, when a student was in a state where his capabilities of going to college were poor, only 10 per cent of the sources communicated pro-college information and 90 per cent communicated information which did not favor his going to college.

We can assume that the teen-ager is interested in choosing a proper action for current information-yielding observations which indicate the existence of one or the other state of affairs possibly prevailing at the moment. In other words, the high school youngster is interested in making a decision as to whether he should follow a_1 or a_2 based on current information state or inputs relative to Q_1 and Q_2, i.e., whether he has or does not have the capabilities of going to college. In short, the student needs to know at some point in time whether he has (or people consider he has) the personality (e.g., the ambition, industry, sociability, responsibility), the interest, and scholastic achievement to warrant being considered a good college candidate.

This brings us to the first problem: how should a rational student go about selecting "optimal" strategies?

A. Problem One: Selection of Criteria for "Optimum" Strategies

The student could list all possible strategies, s, specifying a given action for a given kind of information. Here, s is a rule which tells the student what action should be taken for a given kind of information. Hence, it is possible to list all the possible rules, s, which assign two distinct courses of action of two distinct states of information, yielding four possible strategies, s, in this case (i.e., there are $N_a^{nz} = 2^2 = 4$ possible strategies).

	s_1	s_2	s_3	s_4
z_1	a_1	a_1	a_2	a_2
z_2	a_1	a_2	a_1	a_2

Once all possible different strategies have been enumerated, it is now possible to evaluate the student's average or expected loss of utility, L(Q,s), or the average or expected regret or risk, R(Q,s), for each of the eight strategies. This is done by combining each strategy with the frequency table relating z's to Q's and with student's utility loss or regret tables.

Such a procedure yields the following table of L(Q,s):

L(Q,s)

	s_1	s_2	s_3	s_4
Q_1	0.0	0.4	1.6	2.0
Q_2	7.0	3.4	6.6	3.0

And the risk table, R(Q,s) is:

R(Q,s)

	s_1	s_2	s_3	s_4
Q_1	0.0	0.4	1.6	2.0
Q_2	4.0	0.4	3.6	0.0

The plot of the convex set for average utility loss space for the two states of affairs is shown in Figure 1 below. The regret space (R_1-R_2) is merely the translation of three units up in the L_2 direction as shown. Hence, the shape of the convex set the same for (L_1,L_2) and (R_1,R_2) space.

The double-line boundary represents the set of all pure and mixed admissible strategies or the consequence set of all admissible strategies. Hence, a feasible optimal non-dominated strategy must be a member of this set.

We come now to the problem of how a student should select an "optimal" strategy. Up to this point, it has been indicated how high school youngster is able to construct a decision model relative to his seeking a college education. It may be argued that this model does, indeed, portray his state of affairs and that such a model does provide a logical base or "map" to permit the student to select proper actions for various kinds of information he receives from his social environment. In other words, this model allows the student, in conjunction with various kinds of information about the current situation, to minimize utility loss or regret in comparison to the best possible state of affairs.

We have been able to find which pure or mixed strategies are admissible and which ones are not, i.e., inadmissible. The student, therefore, will have to select one of the admissible pure or mixed strategies. This introduces the selection problem: Which criterion or criteria should be used in selecting one of these admissible strategies as an "optimal" one?

It turns out that the notion, "optimal" is a relative concept, and depends, among other things, upon the student's state of information about his own affairs. For that reason, the rational student has several choices. A conservative approach is to employ the minimax criterion for utility loss. This approach may be used when no knowledge of the probabilities of occurrence of the state

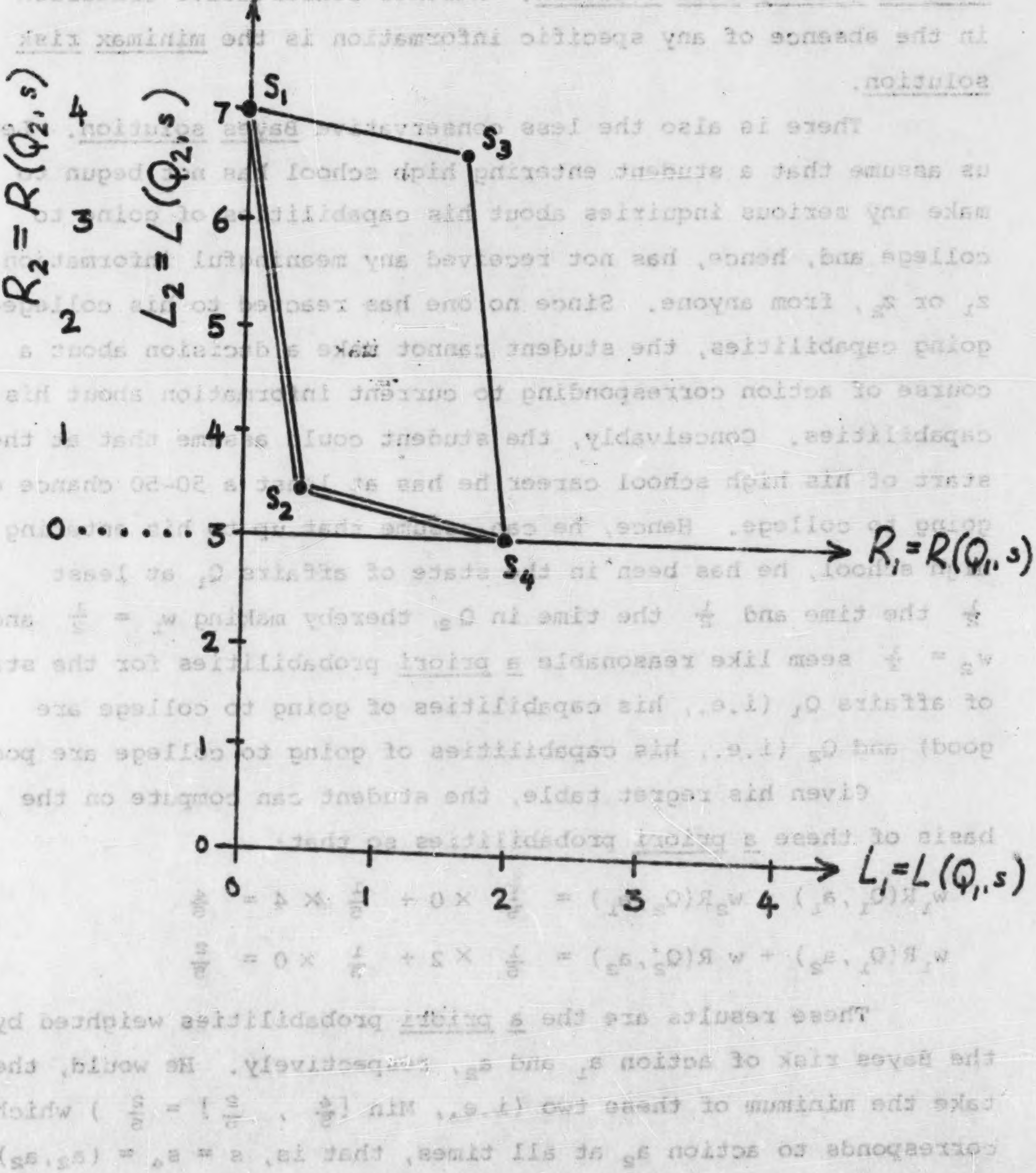
$R_2 = R(Q_2, s)$
$L_2 = L(Q_2, s)$
4
3
2
1
0
7
6
5
4
3
2
1
0
S_1
S_2
S_3
S_4
$R_1 = R(Q_1, s)$
$L_1 = L(Q_1, s)$
0
1
2
3
4

Fig. 1

of affairs is assumed or when this knowledge or any other knowledge of the current situation is not available. This is called the minimax utility loss solution. Another conservative criterion in the absence of any specific information is the minimax risk solution.

There is also the less conservative Bayes solution. Let us assume that a student entering high school has not begun to make any serious inquiries about his capabilities of going to college and, hence, has not received any meaningful information, z_1 or z_2, from anyone. Since no one has reacted to his college-going capabilities, the student cannot make a decision about a course of action corresponding to current information about his capabilities. Conceivably, the student could assume that at the start of his high school career he has at least a 50-50 chance of going to college. Hence, he can assume that up to his entering high school, he has been in the state of affairs Q_1 at least $\frac{1}{2}$ the time and $\frac{1}{2}$ the time in Q_2, thereby making $w_1 = \frac{1}{2}$ and $w_2 = \frac{1}{2}$ seem like reasonable a priori probabilities for the state of affairs Q_1 (i.e., his capabilities of going to college are good) and Q_2 (i.e., his capabilities of going to college are poor).

Given his regret table, the student can compute on the basis of these a priori probabilities so that:

$$w_1 R(Q_1, a_1) + w_2 R(Q_2, a_1) = \frac{1}{5} \times 0 + \frac{1}{5} \times 4 = \frac{4}{5}$$

$$w_1 R(Q_1, a_2) + w \, R(Q_2, a_2) = \frac{1}{5} \times 2 + \frac{1}{5} \times 0 = \frac{2}{5}$$

These results are the a priori probabilities weighted by the Bayes risk of action a_1 and a_2, respectively. He would, then, take the minimum of these two (i.e., $\mathrm{Min}\ [\frac{4}{5}, \frac{2}{5}] = \frac{2}{5}$) which corresponds to action a_2 at all times, that is, $s = s_4 = (a_2, a_2)$. This is the same as the minimax loss and minimax risk solution since the a priori probabilities for the state of affairs make

Q_1 and Q_2 equally likely.

But we can also see what will happen if Q_1 and Q_2 are not equally likely. If, for example, the student's past academic performance is good, say, the top half of his class, then he would set his a priori probabilities of Q_1 so that $w_1 = \frac{2}{3}$ and of Q_2 so that $w_2 = \frac{1}{3}$. This would make the results $a_1 = \frac{4}{3}$ and $a_2 = \frac{4}{3}$. And if the past academic performance were exceptional permitting the student to set $w_1 = \frac{3}{4}$ and $w_2 = \frac{1}{4}$ (e.g., top quarter of the class), then the results would be $a_1 = \frac{4}{4} = 1$ and $a_2 = \frac{6}{4} = 1\frac{1}{2}$. Since 1 is the minimum of the two, he would now select action a_1 at all times, i.e., $s = s_1 = (s_1, a_1)$.

Now this solution is quite different from minimax loss and minimax risk solution for a situation where there is no information from people but the a priori probabilities for the states of affairs, Q_1 and Q_2, are assumed to be known.

The a posteriori method provides still another solution. This method assumes that the student knows both the frequency table of kinds of information, z_1 and z_2, and the a priori probabilities of the state of affairs. Relating these two we have

	z_1	z_2	
Q_1	0.8	0.2	$w_1 = \frac{3}{4}$
Q_2	0.1	0.9	$w_2 = \frac{1}{4}$

The terms in the table are the conditional probabilities of information, z_1 and z_2, given a state of affairs Q_1 or Q_2, i.e., $f(z_j\ Q_i)$. What one is seeking, however, is the conditional probability of Q_i given z_j, i.e., $g(Q_i\ z_j)$. Using Bayes' Theorem, we get

$$g(Q_i\ z_j) = \frac{w_i f(z_j\ Q_i)}{\sum_{k=1}^{n} w_k f(z_j | Q_k)}$$

Thus, one has for these probabilities the following table

	z_1	z_2
Q_1	.97	.39
Q_2	.05	.61

Using the regret table, we can now write the following equations:

$$B(a_1,z_1) = g(Q_1|z_1)R(Q_1,a_1) + g(Q_2|z_1)R(Q_2,a_1)$$

$$= .97 \times 0 + .05 \times 4 = .20$$

$$B(a_2,z_1) = g(Q_1|z_1)R(Q_1,a_2) + g(Q_2|z_1)R(Q_2,a_2)$$

$$= .97 \times 2 + .05 \times 0 = 1.9$$

Then for information z_1 the Min $B(a_1,z_1)$, $B(a_2,z_1)$ = $B(a_1,z_1)$, calling for action a_1. Similarly, one computes $B(a_1,z_2)$ and $B(a_2,z_2)$; the minimum of these two is Min $B(a_1,z_2)$, $B(a_2,z_2)$ = $B(a_1,z_2)$, calling for action a_1.

Thus, one obtains $s = s_1 = (a_1,a_1)$.

Summary. In the foregoing, an attempt has been made to describe the formal relationship between communication and decision-making, or, more specifically, the application of decision theory in choosing an "optimal" strategy in relation to the state of information obtained by some kind of communication activity. A number of attributes of decision theory was investigated. These may be summarized as follows:

1. At any particular point in time, a rational high school student is always able to find an optimal solution in selecting strategies relative to his decision alternatives (e.g., to make or

not make a special effort to get into college, to go or not to go to college).

2. Such a solution can be found no matter how complex the student makes or defines his situation--that is, a solution is possible even when the number of alternatives, number of states of affairs or consequences, and/or the number of observations yielding information are large.

3. Given a decision model, the student is able to deal with several different kinds of information states or information-yielding situations. These include a) the situation where he has access to information obtained from current observation or communication, but where he does not know (and, hence, wishes to find out) about some possible state of affairs; b) the situation where the student has knowledge about past state of affairs, but has no information obtained by current observation or communication, and c) the situation where the student has access to both current information and knowledge about past state of affairs.

4. Even when these various states of information and knowledge are given, there is no unique solution in selecting "optimal" strategies. Instead, there are several such solutions. The kind of solution which a student could obtain depends on his point of view (the way he constructs his decision model), the criterion he uses for selecting "optimal" strategies, and the state of his information. Hence, he is free, for example, to employ the minimax loss approach, the minimax regret approach, the Bayes risk approach or the Bayes strategy or a posteriori approach. Some of the solutions yielded by these approaches may call for the same strategy, but need not. The more common case is where each approach calls for quite different strategies.

5. Since formal decision theory permits a rational student to deal with various kinds of information-yielding situations and with various kinds of strategy selection criteria, it is possible to formally classify student decision-making behavior by these characteristics. And given such a typology of student decision-maker, it is logically possible to predict what kind of college-going decision students will make in the types of student can be empirically identified.

6. Decision theory as outlined above does have certain limitations, however. Such decision theory employs stationary models, that is, models which have static parameters rather than dynamic or time-varying parameters. Critical among these parameters are the communication behavior of the decision-maker and his information inputs. Stationary models admittedly are useful in helping one to describe a particular situation; they yield conclusions which do help in extrapolation. In short, they tell us something about a rational decision-maker: if he utilizes a formal decision model, he can make "optimal" choices from among sets of alternatives relative to a specified set of consequences or outcomes at a specific point in time. Such a model, however, does not tell us a) how the state of alternatives, the state of efficient decision-making, and the state of utilities assigned to outcomes can be, or, in fact, are being, altered by communications over some time increment; nor does it tell us b) what kind of choice behavior the decision-maker will manifest at some future point in time, say, t + n time-units in the future.

B. Problem Two: "Purposeful" Choice Behavior in Relation to the State of Communication[22]

In this section, we shall touch briefly on the problem of communication in building a communication-decision behavior model. Both Ackoff[23] and Martin[24] have dealt with this communication problem relative to decision-making. Their comments can be summarized as follows:

Stated in formal terms, a decision situation is characterized in terms of:

1. A set of alternatives or courses of action;
2. A set of probabilities associated with the alternatives; and
3. A desired set of outcomes which the decision-maker attempts to achieve.

Hence, the decision-maker is required to state his problem and define the alternatives open to him. Information is necessary in assigning weights, values or the probability to each alternative in terms of a set of outcomes.

In other words, the purposeful state of a decision-making situation (or more specifically, a decision-maker) consists of:

D	the decision-maker
$A_1, A_2, \ldots, A_i, \ldots, A_m$	the alternative courses of action where $m \geq 2$
$O_1, O_2, \ldots, O_j, \ldots, O_n$	the possible outcomes of action

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[22] This section deals with the theory of communication advanced by Ackoff and applied by Ackoff and Martin. See footnote 13. In this section an effort is made to show the application of this theory to the information-seeking behavior of college-going students.

[23] Ackoff, op. cit. See Footnote 13.

[24] Martin, op. cit. See Footnote 13.

And the state variables are:

P_i the probability that D will select A_i, i.e., $P(A_i|D)$

E_{ij} the probability that A_i will yield the outcome O_j, i.e., the efficiency of A_i for O_j, such that $P(O_j|D, C_i)$

V_j the relative value (importance or utility) of the jth outcome to D.

We are now able to make a general statement about communications. A decision-maker D_2 is said to *communicate* with another decision-maker D_1 if a message produced by D_2 changes the characteristics of D_1's *purposeful state*, i.e., the message produces a change in D_2's state variables P_i, E_{ij}, or V_j. In the terminology of Ackoff and Martin: to the extent the message affects the probabilities of choice P_i, it is said to *inform*; to the extent that it changes the E_{ij}, it is said to *instruct*; and to the extent that it changes the V_j, it is said to motivate.

This essentially is an effort to formulate operational definitions and measures of the modes of communication and use these measures to evaluate media (both personal and impersonal) which are intended to *communicate* to individuals. These, then, are measures which permit one to evaluate the effectiveness of various modes of communication taken singly or collectively.

A communication *message*, therefore, is viewed as having three possible types of effect and, hence, content. Any message may do any or all of the following: 1) inform (or misinform) an individual by changing the probabilities of choice, i.e., change the state of the alternatives; 2) instruct (or misinstruct) an individual by changing the efficiencies of courses of action, i.e., alter the state of selecting outcomes; and 3) motivate (or demotivate) an individual by changing the values he assigns to outcomes.

In this context, a message is not exclusively restricted to the transmission of information; rather it includes, in addition to information, instruction and motivation. Information refers to what an individual does, instruction to how he does it, and motivation to why he does it.

Now, the effect of a message on the state of the receiving individual is the measure of how much of a change has been made in that state. Hence, we are concerned with a "before-and-after" situation--the state of the receiver immediately before communication (i.e., the initial state) and his state immediately following communication (i.e., the terminal state).

To inform is to provide a basis for choice, giving the individual some reason to believe in the greater efficiency of one choice over another. A unit of information is the amount involved in one determinate choice from two alternatives (a binary choice). The number of information units in a state, say I(S), is given by

$$I(S) = \frac{m}{2} \sum_{i=1}^{m} (P_i - \frac{1}{m})$$

The amount of information communicated may be said to be the difference between the amount of information contained in the receiver's state immediately before communication and the amount of information immediately following communication.

Now let $I(S_1)$ represent the amount of information in the initial state and $I(S_2)$ the amount in the terminal state. The amount of information communicated, I_C is given by

$$I_C = I(S_2) - I(S_1).$$

Instruction, on the other hand, is concerned with modifying the objective probabilities of success, that is, the efficiency. Ackoff and Martin, in conformity with common usage, define instruction to be equivalent to that of "teaching to do more efficiently." Using Ackoff's notations, consider a state containing two courses of action, C_1 and C_2, and two outcomes, O_1 and O_2. A complete lack of instruction would exist in this state if each course of action had no efficiency for either objective; that is, if

$$E_{11} = E_{12} = E_{21} = E_{22} = 0$$

On the other hand, a state of perfect instruction would exist if each course of action had perfect efficiency for each objective; that is, if

$$E_{11} = E_{12} = E_{21} = E_{22} = 1.0$$

Hence, a minimum amount of instruction that can exist in a state is zero and the maximum amount is some function of m and n, say mn, where m is the number of potential courses of action and n is the number of possible outcomes. It follows that the amount of instruction, say (E) in a state is simply equal to the sum of the efficiencies over all potential courses of action for all outcomes; that is

$$E(S) = \sum_{j=1}^{n} \sum_{i=1}^{m} E_{ij}$$

Therefore, the amount of instruction communicated (E_C), to a receiver is the difference in the amount of instruction between the initial and terminal state; that is,

$$E_C = E(S_2) - E(S_1)$$
$$= \sum_{j=1}^{n} \sum_{i=1}^{m} E'_{ij} - \sum_{j=1}^{n} \sum_{i=1}^{m} E_{ij}$$

where E'_{ij} represents the efficiencies in the terminal state and E_{ij} the efficiencies in the initial state. This quantity, E_C, can range from -mn to mn. Negative values represent the loss of efficiency resulting from communication.

Motivation is concerned with values assigned to the outcomes. If an individual assigns equal values to every outcome, he will have no basis for selecting among them and one can say that the individual has no motivation. Given this condition, the measure of motivation can be developed in the exact same way as that used in measuring the amount of information. Hence, the amount of motivation in a state M is given.

$$M(S) = \frac{n}{2} \sum_{j=1} (V_j - \frac{1}{n}$$

And the amount of motivation communicated is

$$M_C = M(S_2) - M(S_1)$$

We can now apply these measures to a high school situation involving a youngster in his freshmen year. Let us assume that at this point in time, the teen-ager is confronted with two courses of action a_1 = elect to go to college and a_2 = elect not to go to college. Suppose further that he is undecided and, hence, has no basis for making a choice; that is

$$P_1(a_1) = P_2(a_2) = \frac{1}{2} = 0.5$$

If the probabilities of selecting the course of action are equal in efficiency, the situation may be said to be indetermined for the student. If he has no basis for a choice, it can be said that he had no information about the alternatives.

However, after having a discussion with his teacher (i.e., receiving communication from his teacher), his information state is changed such that

$$P_1(a_1) = 0.7 \text{ and } P_2(a_2) = 0.3$$

Clearly, the course of action, a_1 = elect to go to college, is now the preferred choice. The amount of information communicated by the teacher can be measured by Ackoff's equation; that is

$$I(S_1) = P_i - \frac{1}{m}$$

$$= 0.5 - \frac{1}{2} = 0$$

and

$$I(S_2) = P - \frac{1}{m}$$

$$= 0.7 - \tfrac{1}{2} = 0.2$$

Hence, the difference between the amount of information in the initial state and that in the terminal state is

$$I_C = I(S_2) - I(S_1)$$

$$= 0.2 - 0.0 = 0.2$$

If, on the other hand, the teacher convinced the student he should elect not to go to college so that the probability of the student choosing college dropped to, say 0.3, then by the equations above we would find that the amount of information about electing to go to college in the student's terminal state would be

$$I(S_2) = 0.3 - \tfrac{1}{2} = -0.2$$

And the amount of information communicated by the teacher would be

$$I_C = -0.2 - 0.0 = -0.2$$

or minus information, representing a loss of information about the alternative a_1, i.e., elect to go to college.

The amount of instruction communicated by the teacher can also be calculated. Suppose the student is asked a series of questions about his qualifications as a potential candidate for college. Assume now that out of this set of questions, say 10, the student could only reply to four (or only answer four questions correctly). The amount of instruction in the student initial state would be $E(S_1) = 0.4$. After talking with his teacher, however, he would be able to reply to eight (or answer eight questions accurately), i.e., $E(S_2) = 0.8$. Hence, the amount of instruction communicated by the teacher is the difference between his initial instruction state and his terminal instruction state; that is

$$E_C = E(S_2) - E(S_1)$$

$$= 0.8 - 0.4 = 0.4$$

Similarly, the amount of motivation communicated in a student-teacher discussion can be calculated by determining prior to the discussion the student's motivation state. As noted earlier, if an individual assigns values equally to all possible outcomes, then he has no basis for selecting among these outcomes.

Since the outcomes used in defining a purposeful state are defined to be exclusive and exhaustive, it follows that the sum of the relative values of these outcomes is always unity, i.e., 1.0; it also follows that if value is added to one outcome, an equal amount must be substracted from the others. This property clearly prevails in the limiting case where there are two contradictory outcomes, O_1 and O_2, such that the individual must select one or the other.

A complete lack of motivation (in the relative sense) would exist in a state if each value was equally likely, i.e., $V_1 = V_2 = . . . V_n = 1/n$; and a state contains maximum motivation when one outcome has the relative value of one and all others have none; that is,

$$V_1 = 1.0, \text{ and } V_2 = V_3 = . . . V_n = 0.$$

Suppose now that a student can choose courses of action which will lead to two different and exclusive outcomes, O_1 = being a college student and O_2 = getting married and being a housewife or enlisting in the Army and being a soldier. Assume he assigns utilities to these outcomes which take the values $V_1 = 0.4$ and $V_2 = 0.6$. Employing Ackoff's equation described above, we would have as the amount of motivation in the initial state relative to outcome O_1

$$U(S_1) = V_j - \frac{1}{n}$$

$$= 0.4 - \tfrac{1}{2} = -0.1$$

And after a discussion with his teacher, the student's utility state might take the value 0.6 for outcome O_1; that is

$$U(S_2) = V_j - \frac{1}{n}$$

$$= 0.6 - \tfrac{1}{2} = 0.1$$

Hence, the amount of motivation communicated by the teacher (i.e., the measure of how much the student was motivated) is given by

$$U_C = U(S_2) - U(S_1)$$

$$= 0.1 - (-0.1) = 0.2$$

Given the above measures of the amounts of information, instruction, and motivation, it is also possible to develop an expression for the value of a communication. The value of a communication, including all three communication modes, can be defined as the value of the terminal state minus the value of the initial state; that is

$$V_C = V(S_2) - V(S_1)$$

$$= \sum_{i=1}^{m} \sum_{j=1}^{n} (P_i + \Delta P_i)(E_{ij} + \Delta E_{ij})(V_j + \Delta V_j) - \sum_{i=1}^{m} \sum_{j=1}^{n} P_i E_{ij} V_j$$

where ΔP_i, ΔE_{ij}, and ΔV_j represent the change in state variables between S_1 and S_2. This equation, when expanded, yields an expression which takes into account the value added to the initial state by information, instruction, and motivation and the value of the joint contributions, i.e., the values of the various possible interactions.

Summary. In the foregoing, a formal communications model was described. In dealing with the relationship between communication and decision-making, certain decision parameters were taken as fixed while investigating the interrelationship of various components in a communication system. In this section the concern was focused on the application of communication theory in describing change in the "purposeful" behavior of an individual. Some of the conclusions which may be derived from this analysis may be summarized as follows:

1. At any specific point in time, the high school student's purposeful state can be described in terms of how it differed from a pervious state. More formally, communication theory permits one to say that one decision-maker in fact communicates with another decision-maker (say, a high school student) to the extent that the message produced by the first decision-maker produces a change in the high school student's purposeful state.

2. The purposeful behavior of an individual decision-maker is defined in terms of three state variables: a) the probability that the decision-maker receiving the message will select a specific alternative or course of action; b) the probability that a particular alternative will yield a specific outcome or consequence, and c) the relative value (i.e., importance or utility) assigned or attached by the decision-maker to a specific outcome.

3. This theory of communication permits one to describe a student's communication behavior no matter how complex the student makes his communication situation--that is, a solution is possible even when the number of alternatives and outcomes, the number of communication sources, and the number of messages are large.

4. Given a communication model, the student is able to deal with several different kinds of purposeful states or communication situations. These situations are defined in terms of communication modes, taken separately or in combination. This yields a typology of communication situations with six possible different types.

5. With these modes of communication it is possible to logically classify student communication behavior by the modal characteristics; and given a typology of communication behavior,

it is formally possible to predict what kind of communication activity the student will perform if such types can be empirically identified.

6. This communication theory assumes change or a transition over time--that is, a change between the initial state and the terminal state which are defined as two fixed points in a time dimension. Hence, the model makes the measure of the amount of communication a function of the difference between the separate but time-fixed states.

7. The communication model also permits us to explain logically how communication can (or, in fact, does) affect decision-making behavior since changes in the individual's communication state change the parameters in decision-making behavior. Once, however, a new set of values has been provided by a communication, the decision-maker is able to solve for an "optimal" choice; but this choice, in turn, changes the parameters in communication behavior.

8. Hence, the limitations in communication theory is to be found in the inability to predict a) how the decision-maker will build his decision model, b) what criterion or criteria he will use in selecting strategies, and c) how the interaction of communication behavior and decision behavior will affect his social behavior extended through time.

V.

SECOND STEP IN DESIGNING A COMMUNICATION-DECISION MODEL: TIME-DEPENDENT COMMUNICATION BEHAVIOR IN RELATION TO THE STATE OF DECISION

In the previous section, we have alluded to the need for a communication-decision model which permits one to measure changes in the "purposeful" state of an individual resulting from communication and at the same time determine how and what "optimal" choices are made in decision behavior.

In other words, the problem may be stated more simply in this fashion: what one desires to know is, given a series of message inputs over time under circumstances where these messages are affecting the "purposeful" state of the individual, when does an individual arrive at a point where he makes a decision and what kind of decision does he make at this point?

A first step in an attack on this "time-dependent" problem is to think of communication-decision behavior as 1) incremental decision making in a sequence over time, and 2) incremental communication in a sequence over time.

Let us begin with incremental decision making. Suppose we view the decision-maker engaged in a "game." This game can be played with either "nature" or with "opponents." As to whether we elect to think in terms of "nature" or "opponents" is determined by the assumption one wishes to make about his environment. Nature, for example, may be either physical nature or a social system or another person. The distinction between these two concepts is to be found in assuming that the environment will or will attempt to maximize its advantage (or minimize its disadvantage) at your expense--that is, where your loss will be his gain.

In the case of a high school student seeking to get into college, one is permitted to view the college environment as a "state of nature" on the assumption that the loss in utility which a student suffers by being refused admission cannot be translated directly into a college's utility gain.

Further, suppose that we view a student's decision about going or not going to college as a sequence of decisions over time. Each decision-making activity becomes a "game" with nature.

Suppose a student has two strategies, two states of nature, and two courses of action:

His strategies, s_1 and s_2, are 1) to inquire about his state of affairs, and 2) not to inquire.

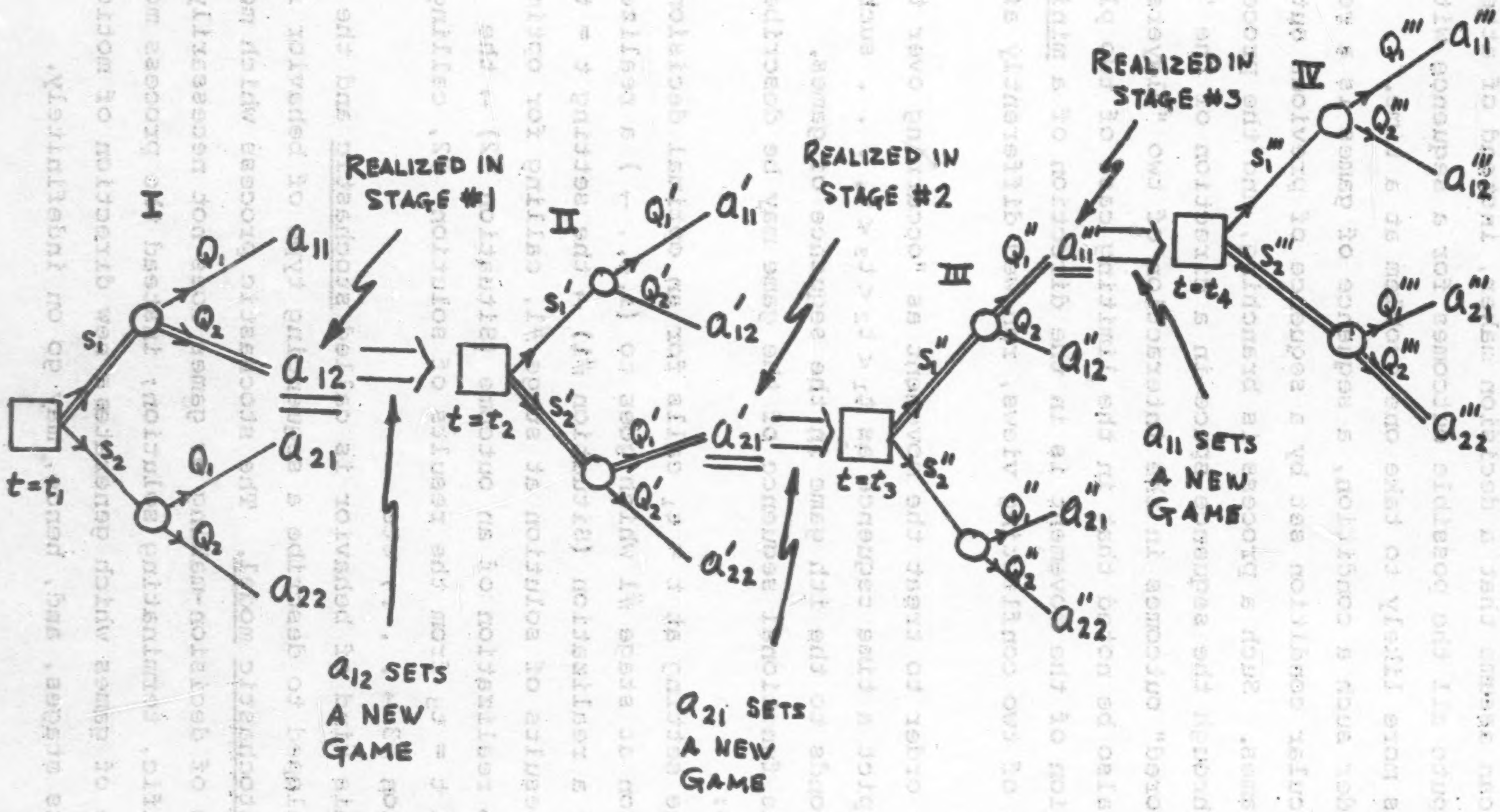
His states of nature, Q_1 and Q_2, are 1) a set of good qualifications and capabilities as a potential candidate for college, and 2) a set of poor qualifications and capabilities.

His courses of action, a_1 and a_2, are 1) to take positive steps toward getting admitted to college, and 2) to take no such action.

Suppose further that the student wishes to know (i.e., to assess) his college-going potential relative to three situations: 1) his financial capabilities; 2) his scholastic qualifications, and 3) his personality qualifications.

Figure 2 depicts the sequence of decision-making or games in which he engages over a period of time, say t + 4 time units. It will be noted that the results or consequences of the previous game sets a stage for the subsequent game. In this way, from among a diversity of many multiplied possibilities only one path is selected or plotted.

It also should be noted that for the rather simple two-strategy, two-outcome case with n-number of games in a sequence, there could be altogether 4^n possible different end results. In our case this would be $4^4 = 256$ possibilities.


REALIZED IN STAGE #1
REALIZED IN STAGE #2
REALIZED IN STAGE #3
I
II
III
IV
$t=t_1$
$t=t_2$
$t=t_3$
$t=t_4$
s_1
s_2
Q_1
Q_2
a_{11}
a_{12}
a_{21}
a_{22}
s_1'
s_2'
Q_1'
Q_2'
a_{11}'
a_{12}'
a_{21}'
a_{22}'
s_1''
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Q_1''
Q_2''
a_{11}''
a_{12}''
a_{21}''
a_{22}''
s_1'''
s_2'''
Q_1'''
Q_2'''
a_{11}'''
a_{12}'''
a_{21}'''
a_{22}'''
a_{12} SETS A NEW GAME
a_{21} SETS A NEW GAME
a_{11} SETS A NEW GAME

FIG. 2

Hence, we can assume that a decision maker, instead of attempting to compute all the possible outcomes for a sequence with n games, is more likely to take one problem at a time.

Under such a condition, a sequence of games is a result of a particular condition set by a sequence of previous outcomes of games. Such a process is branching, and the process diffuses through the sequence space in a direction of the "most likely favored" outcomes in the interaction of two "players." It should also be noted that in the limiting case of two players, the direction of the movement is in the direction of a minimax compromise of two conflicting views, renewed differently after each play.

In order to treat the movement as "occurring over time," one can depict a time sequence as $t_1 < t_2 < t_3 < t_4$ . . . such that t_1 corresponds to the ith game in the sequence of games.

The functional sequence of the game may be described as follows:

The setting at $t = t_1$ calls for an optimal decision or optimization at stage #1 which goes to (i.e., →) a realized outcome or a realization (Situation #1) → the setting $t = t_2$ from the results of solution at stage #1, calling for optimization #2 → realization of an outcome (Situation #2) → the setting at $t = t_3$ from the results of solution #2, calling for optimization #3 → . . ., etc.

This kind of behavior is called stochastic and the model developed to describe a sequencing type of behavior is called a stochastic model. The stochastic process which models a sequence of decision-making or games does not necessarily lead to a specific, terminating solution; instead the process models a sequence of games which generates a new direction of motion at each of its stages, and, hence, may go on indefinitely.

Figure 2 may also be employed to depict a sequence of communication. If an individual, for example, is indecisive about which alternative to select he is in a state of indeterminism and, hence, has no basis for making a choice. He may, therefore, elect to engage in communication to reduce his indeterminism so that he can increase the probability of selecting one of the alternatives. To the extent that he receives a message from another increasing his probability of selection, he has been informed at, say, stage #1 at $t = t_1$. The change in the individual's purposeful state at #1 calls for communication at stage #2 at $t = t_2$, and so on.

We have now arrived at a critical point in our model-building effort, namely, the development of a single model to describe communication-decision behavior. It will be noted, from the analysis presented above, that there is convergence of the decision model and the communication model when one attempts to depict behavior stochastically.

Suppose we are given at some point in time $t = t_1$ a simple two-by-two matrix, say $Q^{(t=t_1)}$, relating alternatives a_1 and a_2 to outcomes O_1 and O_2 as follows:

$$Q^{(t=1)} = \begin{array}{c|cc} & O_1 & O_2 \\ \hline a_2 & 0.9 & 0.1 \\ a_2 & 0.4 & 0.6 \end{array}$$

The cell values, i.e., E_{11}, E_{12}, E_{21}, and E_{22}, represent the joint occurrences (or, in this case, the joint probabilities) such that

$$E_{11} = f(a_1, O_1) = 0.9$$

$$E_{12} = f(a_1, O_2) = 0.1$$

$$E_{21} = f(a_2, O_1) = 0.4$$

$$E_{22} = f(a_2, O_2) = 0.6$$

The matrix, itself, may be regarded as the state of communication at time $t = t_1$, and the content of this communication may be information, instruction, or motivation, or any combination of these. Now referring back to what was discussed in our analysis of decision-making, we know how to proceed in choosing the "optimal" strategy--that is, some s^*, say s_j, such that s_j is some combination of a's, say a_1 and a_1 or a_1 and a_2, i.e., $s^* = s_j = (a_i, a_i)$. A decision, therefore, is made, given some state of communication (in this case, the state of information since we are concerned with the probabilities assigned to alternatives) and the criterion which are used to make an "optimal" choice.

Suppose now that we take the same set of alternatives and the same set of outcomes and look at matrix Ω at $t = t_2$ with these changes in the cells:

$$\Omega(t=t_2) = \begin{array}{c|cc} & O_1 & O_2 \\ \hline a_1 & 0.6 & 0.4 \\ a_2 & 0.8 & 0.2 \end{array}$$

We may now ask what has happened? To this sweeping question there are, of course, several answers.

If we look at the matrix in terms of the state of information it contains, then we could be interested in the changes which occurred in the cells--that is, the difference between the cell values in matrix $\Omega^{(t=t_2)}$ as compared with the cell values in $\Omega^{(t=t_1)}$. Since these differences can be computed, we are able to speak in this case of the amount of information communicated by whatever agent or system brought about the difference or/and the amount of information communicated over discrete time units.

If we use Ackoff's equations, we would derive measures indicating that there was more determinism in a_1-row of $\Omega^{(t=t_1)}$ than is found in the same row of $\Omega^{t=t_2)}$. Hence, information has been lost in moving from $t = t_1$ to $t = t_2$. By the same logical, we also know that determinism has increased in a_2-row, and, hence, there has been a gain in the amount of information.

Suppose that at $t = t_3$ the matrix changed to the following state:

$$\Omega(t=t_3) = \begin{array}{c|cc} & O_1 & O_2 \\ \hline a_1 & 0.5 & 0.5 \\ a_2 & 0.8 & 0.2 \end{array}$$

We can now see that the a_1-row has been reduced to complete indeterminism; there is here no basis for a choice or decision.

If these matrices are taken to represent discrete states in an individual moving in a time continuum, then there are several things one can say about these changes:

1 If an individual is to choose between two outcomes O_1 and O_2 by selecting alternative a_1, then we can see that in three moves his information state has changed from a high amount of certainty about obtaining O_1 given a_1 (i.e., the conditional probability, $f(O_1 : a_1) = 0.9$) to a low amount of information and his decision state has changed from a high amount of determinism (i.e., he has high basis for making a choice) to indeterminism (i.e., he has no basis for making a decision).

2. If, however, the individual develops uncertainty and indecisiveness about a_1, he can look for a better route to get to his desired outcome; hence, he can choose between a_1 and a_2. Now the a_2-row contains not only a higher amount of determinism than found in the a_1-row but also a higher amount of certainty about obtaining O_1 given a_2. In other words, he is in the position to choose not only between O_1 and O_2 given a_2, but also between a_1 and a_2 given O_1. And this he can do for two reasons: first, because the amount of information contained in the (a_2, O_1)-cell is high as measured on a certainty-uncertainty continuum, and

second because the amount of information communicated over time as measured on a determinant-indeterminant continuum has increased in the a_2-row, and specifically, in the (a_2, O_1)-cell. What this says in essence is that if an individual prefers a_1 and O_1, and a_1 turns out to be suboptimal, then he must choose another alternative, i.e., if the end is important then a new means must be found.

3. But there is still another approach. If the individual has a strong preference for a_1 then he is required to change his preference for O_1 and O_2, i.e., if the mean is important then a new outcome must be found. In this case he would have to switch to O_2.

4. There are some additional options open to him. He can 1) select a new set of alternatives to achieve his objective, 2) select a new set of objectives, or 3) do both.

5. Finally, he can hold on doggedly to his preferred alternative and outcome and "suboptimize," i.e., take his loss or suffer his regret when he fails to succeed.

So far we have been talking about making a decision, given information and communication--that is, the values in the matrix cells provide the basis for making decisions. Once a decision has been made, however, the state of the individual changes; instead of looking at the values of matrix cells to guess or predict what the outcomes will be, he now produces a matrix with the value in one cell set at unity (i.e., 1.0) and the value of all other cells set at 0. This is,

	O_1	O_2
a_1	0.0	0.0
a_2	1.0	0.0

When this condition occurs, we know that an individual has arrived at a decision or made a choice. The problem, of course, is to design a model which will allow one to trace such communication-decision behavior over time until it reaches some "terminal" state. The questions related to this problem are: 1) how many moves or steps will it take to get into a terminating state? and 2) what kind of state will it be?

If we focus on the last question, we may wish to interpret the terminating matrix above as the end of a decision sequence and the beginning of a communication sequence. Earlier we said that we have been talking about making a decision, given information and communication. We now can take the inverse of this and focus on obtaining information through communication, given a decision.

The terminating matrix may have been generated in the following manner. Suppose an individual takes the information contained in matrix $Q^{(t=t_3)}$ and the information communicated from one matrix to another, beginning with matrix $Q^{(t=t_1)}$ and selects one of the outcomes. Suppose further that he defines his outcomes as follows: If a value goes to unity in the O_2-column this will mean that he has all the information he needs and no further inquiries will be made (i.e., communication will be stopped); if a value goes to unity in the O_1-column this will mean that he lacks information and further inquiries will be made.

Arriving as he does in the O_1-column, he has in effect made a decision to obtain more information through more communication.

In the foregoing, we have touched on some of the complexity in the communication-decision process. What is needed is a model which will permit one to reduce this complexity by some economical means to a set of patterns which can be displayed and analyzed. To do this a more formal method will be employed, namely, the mathematics of the stochastic process and the Markov chain.

A. Solution One: A Communication-Decision Model with Constant Transition Matrices or Incremental Behavior in a Sequence Over Time

Any process which has a random element as part of its structure is called a stochastic or probability process, i.e., any process with a time dimensioned and controlled by the laws of probability.[25] Doob has defined a stochastic process as "any family of random variables (x_t , t &T)." "Here x_t is in practice the observation at time t and T is the time range," he said.[26] Kemeny and Snell have defined a finite stochastic process as an independent process such that "for any statement p whose truth value depends only on the outcomes before the n-th"

(1) $\text{Prob}(X^{(t)} = x_j | p) = \text{Prob}(X^{(t)} = x_j)$.[27]

In other words, the probability that the value of any possible outcome function $X^{(t)}$, $t = 0,1,2, \ldots$, is equal to x_j given p is simply equal to the probability that $X^{(t)} = x_j$ without any knowledge of p. In such a process the outcome of any preceding event does not affect predictions about the next event. If one weakens this statement to allow knowledge of the immediate past to affect the immediate future, the Markov principle is introduced.

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[25] Joseph L. Doob, Stochastic Processes (New York: John Wiley & Sons, Inc., 1953), pp. 46-47.

[26] Doob said about his definition, "Our definition of a stochastic process is embarrassingly inclusive in that there are not many problems in probability that cannot be formulated as problems in families of random variables. Historically, however, the term stochastic process has been reserved for families (usually infinite) of random variables with some simple relationship between the variables . . ." ibid., p. 47.

[27] John G. Kemeny and J. Laurie Snell, Finite Markov Chains (New York: D. Van Nostrand Company, Inc., 1960), p. 24.

The term "Markov process" refers to a large class of stochastic processes with both discrete and continuous time parameters. A Markov process can be conceptualized as a probabilistic analogue of the process of mechanics where the development of the future is independent of the way in which the past was formed. In formal terms Feller has defined a Markov process as a sequence of discrete-valued random variables such that for every finite collection of integers $t < t+1 < t+2 < . . . < t+n$ the joint distribution of $(X^{(t)}, X^{(t+1)}, . . . , X^{(t+n)})$ is defined in such a way that the conditional probability of $X^{(t+n)} = x$ on the hypothesis that $X^{(t+i)} = x_i$ $(i=0,1,2, . . . ,n-1)$ is identical with the conditional probability of $X^{(t+n)} = x$ on the single hypothesis $X^{(t+n-1)} = x_{n-1}$ at time $t+n-1$. In this case any x_i $(i=1,2, . . . ,n)$ is an arbitrary number such that the hypothesis has a positive probability.[28] In simpler terms, given a state x_{n-1} at time $t+n=1$, additional data about the system at previous times will not affect the probability of state x at future time $t+n$.

The same principle with a little different notation has been given by Kemeny and Snell. They defined a Markov process with finite elements as one such that for any statement p whose truth value depends on the outcomes before the t-th event

$$(2) \quad \text{Prob}(X^{(t)}=x_j|X^{(t-1)}=x_i \text{ \& } p)=\text{Prob}(X^{(t)}=x_j|X^{(t-1)}=x_i).$$[29]

Both definitions state the same property (Markovian principle), i.e., given any state at some point in time t, the past history of the development of the state does not affect the future of the state. Such a process requires that one have exact knowledge of the outcome of the last state in order to predict the future.

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[28] William Feller, An Introduction to Probability Theory and Its Applications, I (New York: John Wiley & Sons, Inc., 1950), p. 369.

[29] Kemeny and Snell, op. cit., p. 24.

Bartlett has noted that for such a process the simultaneous distribution at time t (t=1,2, . . . ,n) is

$$(3)\quad \text{Prob}(x_1, x_2 . . . . , x_n) = \text{Prob}(x_1)\text{Prob}(x_2|x_1)\text{Prob}(x_3|x_1, x_2). . . \\ = \text{Prob}(x_1)\text{Prob}(x_2|x_1)\text{Prob}(x_3|x_2). . . \\ = \text{Prob}(x_1) \prod_{r=1}^{n} \text{Prob}(x_r|x_{r-1}).^{30}$$

A Markov process is then defined by the conditional distribution $\text{Prob}(x_r|x_{r-1})$ for any r (r=1,2, . . . ,n) and an arbitrary choice of the set t (t=1,2, . . . ,n) and an initial distribution $\text{Prob}(x_1)$.[31]

Applying an integral operator to the above equation, Bartlett obtained:

$$(4)\quad \text{Prob}(x_r\ x_{r-2}) = \int_{x_{r-i}} \text{Prob}(x_r, x_{r-i}|x_{r-2}) \\ \int_{x_{r-1}} \text{Prob}(x_r|x_{r-i}, x_{r-2})\text{Prob}(x_{r-i}|x_{r-2}) \\ \int_{x_{r-1}} \text{Prob}(x_r|x_{r-1})\text{Prob}(x_{r-1}|x_{r-2}).$$

This is known as the Chapman-Kolmogorov equation, and from repeated application of the equation $\text{Prob}(x_r\ x_1)$ can be obtained. The formula for $\text{Prob}(x_r)$ is then

$$(5)\quad \text{Prob}(x_r) = \int \text{Prob}(x_r|x_1)\text{Prob}(x_1).^{32}$$

Another way of writing the Chapman-Kolmogorov equation has been given by Feller as

$$(6)\quad \text{Prob}(X_{in}^{(r,t)}) = \Sigma\ \text{Prob}(X_{iv}^{(r,s)})\text{Prob}(X_{vn}^{(s,t)}).$$

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[30] Bartlett has noted that this seems a severely restricted definition of a Markov process but that in reality many processes fall within this definition when they are conceptualized by vector and matrix notation. Two examples he gave included the velocity as well as the position of a particle in classical physics which are required before the future motion of the particle can be predicted and the prediction of the number of births in a year based on the number of individuals in all age groups at that time rather than the past history of birth trends. Ibid., pp. 24-25.

[31] Ibid., p. 25.

[32] Ibid.

Feller has defined the left side of the equation as the conditional probability of finding the process at time t in state n given that the process was in state i at time r where $r < t$. This definition is based on the conclusion that the passage of the process from state j at time r to state n at time t must occur by way of some state v at time s.[33]

If the values of the system A can be assumed discrete, the Markov process can be written in matrix and vector notation.[34] In general this means that $q_{ij}^{(t)}$ can be defined as the transition probability that the process will move from state i to state j at time t, i.e.,

$$(7) \quad q_{ij}^{(t+1)} = \text{Prob}(A^{(t+2)} = i \;\; A^{(t)} = j).$$

To entirely specify this process, a probability vector is necessary. Such a vector might be called P. P has elements p_i $(i=1,2, \ldots ,m)$ where p_i is the probability that system $A^{(t)}$ will be in state i or a_i at time t. In this case $\sum_{j=1}^{m} q_{ij}^{(t)} = 1$ $(i=1,2, \ldots ,m)$ and $\sum_{i=1}^{m} p_i^{(t)} = 1$. At any time state j could occur in one of m ways, i.e., the process could remain in state j if it was in this state at time t-1 or the process could move from any state k $(k \neq j)$ to state j if it was in state k at time t-1. Therefore, the probability that a_j will occur at time t+1 or $p_j^{(t+1)}$ is

$$(8) \quad p_j^{(t+1)} = p_1^{(t)} q_{1j}^{(t+1)} + p_2^{(t)} q_{2j}^{(t+1)} + \ldots + p_m^{(t)} q_{mj}^{(t+1)}$$
$$= \sum_{i=1}^{m} p_i^{(t)} q_{ij}^{(t+1)} \qquad (j=1,2, \ldots ,m).$$

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[33] Feller, op. cit., pp. 423-24.

[34] A matrix is a rectangular array of elements arranged in rows and columns. A column vector is a matrix with one column, and a row vector is a matrix with one row. See, for example, Nathaniel Macon, Numerical Analysis (John Wiley & Sons, Inc., 1963), pp. 41-43.

Such a process is called a Markov chain.[35] A finite Markov chain is a process where there is a finite number of possible states. A special case of the Markov chain and the one which has been most often studied is the case where the transition probabilities $q_{ij}^{(t)}$ do not depend on the time element t in which case they are denoted by q_{ij}.[36]

If the probability vector $P^{(t)}$ is defined as a set of possible states in which some process can go, then

$$(9)\quad P^{(t)} = (p_1^{(t)}, p_2^{(t)}, \ldots, p_m^{(t)}),$$

and if $Q^{(t)}$ is the set of all transitional probabilities,

$$(10)\quad Q^{(t)} = \begin{array}{ccccc} q_{11}^{(t)} & q_{12}^{(t)} & \cdots & q_{1m-1}^{(t)} & q_{1m}^{(t)} \\ \vdots & \vdots & & & \vdots \\ q_{i1}^{(t)} & q_{i2}^{(t)} & \cdots & q_{im-1}^{(t)} & q_{im}^{(t)} \\ \vdots & \vdots & & \vdots & \vdots \\ q_{m1}^{(t)} & q_{m2}^{(t)} & & q_{mm-1}^{(t)} & q_{mm}^{(t)} \end{array} .$$

Equation 8 can be written as

$$(11)\quad P^{(t+1)} = P^{(t)}\, Q^{(t+1)}.$$

This means that the elements of vector P at time t+1 are determined by the multiplication of vector P at time t by the transitional matrix Q at time t+1.[37]

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[35] Murray Rosenblatt, Random Processes (New York: Oxford University Press, 1962), pp. 36-37.

[36] Bartlett has noted that some writers restrict use of the term "chain" to only discrete time processes whereas the two main classes of Markov chains are divided by the nature of the time element t. A further subdivision is according to the number of states, finite or infinite. Bartlett, op. cit., p. 26.

A Markov chain can be illustrated in a case where there are just two possible states, i.e., m=2. Alternative one can occur at time t+1 in either of two ways, i.e., it follows itself or it follows alternative two. The same is true for alternative two. This gives the following two equations:

$$p_1^{(t+1)} = p_1^{(t)} \cdot q_{11}^{(t+1)} + p_2^{(t)} \cdot q_{21}^{(t+1)}$$

$$p_2^{(t+1)} \quad p_1^{(t)} \cdot q_{12}^{(t+1)} + p_2^{(t)} \cdot q_{22}^{(t+1)}$$

In matrix form this would be

$$\begin{bmatrix} p_1^{(t+1)} & p_2^{(t+1)} \end{bmatrix} = \begin{bmatrix} p_1^{(t)} & p_2^{(t)} \end{bmatrix} \cdot \begin{bmatrix} q_{11}^{(t+1)} & q_{12}^{(t+1)} \\ q_{21}^{(t+1)} & q_{22}^{(t+1)} \end{bmatrix}$$

In the case of a Markov chain with stable transitional probabilities, the equation becomes

$$(12) \quad P^{(t+1)} = P^{(t)} \cdot Q.$$

Kemeny and Snell have noted that successive application of equation 11 suggests

$$(13) \quad P^{(t+1)} = P^{(0)} \cdot Q^{(1)} \cdot Q^{(2)} \cdot \, . \, . \, . \cdot Q^{(t+1)}$$

or in the case of a finite Markov chain with stable transitional probabilities

$$(14) \quad P^{(t+1)} = P^{(0)} \cdot Q^{t}$$

where Q is raised to the power t.[38]

A short review of some special kinds of Markov chains is

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[37] Matrix multiplication of two matrices A and B is defined only if the number of columns of A and the number of rows of B are identical. If A has i columns and j rows and B has k columns and i rows, then their product is matrix C with k columns and j rows. Notationally this is

$$c_{jk} = a_{j1}b_{1k} + a_{j2}b_{2k} + \, . \, . \, . \, + a_{jm}b_{mk} = \sum_{i=1}^{m} a_{ji}b_{ik} \, .$$

[38] Kemeny and Snell, op. cit., pp. 32-33.

necessary. A Markov chain is a regular chain if some power of the transition matrix contains only positive elements. If a transition matrix Q is part of a regular chain, the powers of Q approach some limit D, i.e., $Q \rightarrow D$. The limiting matrix D contains all positive elements, and each row of D is the same probability vector V. Vector V can be called a fixed vector for Q such that $V \cdot Q = V$.[39]

This convergence to a stable matrix demonstrates that since $q_{ij}^{(t)}$ is the probability that the process will be in state j after t transitions if the process started in state i, the transitional elements for t or the long-range predictions are about the same for all transitions. This means that the probability of being in any state i is approximately v_i which is independent of the starting states of the process.

A Markov chain in which it is possible to go to every state from every other state is called an ergodic chain.[40] A regular chain is therefore an ergodic chain, but an ergodic chain need not necessarily be a regular chain.[41] If a Markov chain is ergodic, there exists a unique probability vector U such that $U \cdot P = U$. It can also be shown that for an ergodic chain if $c_j^{(t)}$ is the average number of times the Markov chain is in state j in the first t steps then for any $e > 0$, $\mathrm{Prob}(c_j^{(t)} - u_j > e) \rightarrow 0$.[42]

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[39] John G. Kemeny et al., Finite Mathematical Structures (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1958), pp. 391-93.

[40] Ibid., p. 394.

[41] On any one step the probability of being in a particular state may be zero for an ergodic chain no matter how large the power to which the matrix has been raised.

[42] Kemeny et al., op. cit., p. 394.

If any state in a Markov chain is such that it is possible to enter it but impossible to leave it, then this is an absorbing state. A Markov chain is absorbing if it contains at least one absorbing state and if it is possible to go to an absorbing state from every state. If a Markov chain is absorbing then the probability that the process will be absorbed is one. An outline of the proof of this statement can be given. If r_j is the probability that the process will be absorbed and s_j is the probability that the process will not be absorbed starting from state j in n_j steps, then both r_j and s_j are less than one. If s is the largest of the s_j and n is the largest of the n_j, the probability that the process will not be absorbed in n steps is less than s. The probability of not being absorbed in 2n steps is s^2, etc. Since s is less than one, these probabilities approach zero, and the probability that the process will be absorbed approaches one.[43]

The key to a discussion of Markov chain theory is the transition matrix. In a Markov chain with stationary transition elements, once the values of these elements have been specified the outcome of the process is completely determined. In other words, no matter what the values of any initial probability vector, the Markov chain will always converge to a unique vector such that the product of this vector and the transition matrix is the unique vector again. This may be illustrated in a simple example.

In this example we would like to know the probability that a man will read his newspaper or watch television on any given evening. From previous experience we know that in a 110-day period he read his newspaper a total of 50 days, and in this same period he watched television a total of 100 days. He watched television and read his newspaper in the same day on

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[43] *Ibid.*, pp. 404-406.

40 occasions. If N represents the days of newspaper reading, T the days of television watching, and NT the days of doing both, the following table can be constructed:

1	N-NT = 10	NT = 40
2	NT = 40	T-NT = 60

Since the sum of row one is 50 and the sum of tow two is 100, the following percentages can be obtained by dividing each element in the matrix by the sum of its row:

$$\begin{array}{c|cc} & 1 & 2 \\ \hline 1 & .2 & .8 \\ 2 & .4 & .6 \end{array}$$

where element 1-1 is the probability of only reading the newspaper and elements 1-2 and 2-1 are the probabilities of reading the newspaper and watching television. Element 2-2 is the probability of just watching television. Since this matrix is defined this way, it can be a transition matrix and can be a part of a Markov chain to be used in predicting the probabilities of reading the newspaper and watching television over a series of evenings. Beginning with an initial vector where state 1 (the probability of reading the newspaper) equals .4 and state 2 (the probability of watching television) equals .6, the following series can be obtained:

	1	2
t=0	.400	.600
t=1	.320	.680
t=2	.576	.424
t=3	.285	.715
t=4	.333	.667
t=5	.333	.667

This series converges to a stable vector in four transitions where the probability of reading the newspaper is .333 and of watching television .667. The same vector would have been obtained if the initial vector had been (.100 .900) or even if it had been (.900 .100).

A Markov chain with several possible states can be illustrated by the data obtained from Syracuse University freshmen in 1962 and 1963. The focus of this chain is the prediction that a student will talk with any particular member of the interpersonal group of sources as defined above. The transition matrix which can be called C contains elements c_{ij}. Each element is the probability that the student will talk to source j and then to source i. Defining the process in this way the probability of talking to any given source over time can be analyzed.

Time is assumed to be discrete. If a student talks to someone, a time point t is created, and each time he talks with someone new a new time point is established. The lower bound of any unit of time is the start of a communication tact at which point a new time unit begins.

The values of matrix C can be obtained from the empirical data. A matrix called Y can be constructed such that each element y_{ij} is the number of students in 1962 and 1963 who said they talk with source i and with source j. The diagonal elements of Y (that is, y_{ij} where $i=j$) indicate the total number of students who said they talked with source i and to no one else. Such a matrix is symmetrical. Using Y the elements of C can be obtained from the following definition:

$$c_{ij} = \frac{y_{ij}}{\sum_{k=1}^{m} y_{ik}} \qquad (i \text{ and } j = 1,2, \ldots ,m).$$

This means that the elements of any row i of matrix C are obtained by dividing the corresponding element of matrix Y by the sum of the elements in row i. The resulting percentage is the probability that the student will talk with source i and to source j. This matrix is shown in Table 1. It is not symmetrical since the sums of the rows are not equal. As there were few if any students who said they talked with only one source and to no others, the

TABLE 1

TRANSITION MATRIX C--SOURCE TO SOURCE PROBABILITIES
(COMBINED 1962-1963 RESPONSES)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.000	.105	.066	.082	.106	.083	.097	.072	.066	.047	.051	.086	.076	.053	.009
2	.109	.000	.067	.084	.105	.083	.096	.072	.065	.046	.050	.085	.075	.053	.009
3	.103	.100	.000	.085	.097	.081	.093	.073	.063	.044	.048	.081	.071	.052	.009
4	.103	.102	.069	.000	.101	.083	.095	.074	.063	.044	.047	.085	.074	.051	.008
5	.109	.104	.065	.083	.000	.085	.097	.072	.065	.047	.051	.087	.076	.053	.008
6	.104	.099	.065	.083	.102	.000	.095	.074	.063	.047	.050	.085	.074	.051	.008
7	.106	.102	.066	.083	.103	.084	.000	.073	.065	.047	.050	.085	.075	.053	.008
8	.102	.099	.067	.084	.099	.084	.094	.000	.061	.044	.047	.085	.076	.050	.008
9	.103	.096	.063	.078	.098	.078	.092	.066	.000	.057	.057	.080	.070	.053	.010
10	.097	.091	.059	.072	.094	.077	.088	.063	.076	.000	.070	.078	.069	.053	.011
11	.099	.093	.061	.073	.096	.078	.089	.064	.072	.066	.000	.078	.067	.051	.011
12	.104	.099	.063	.081	.101	.082	.094	.072	.063	.046	.048	.000	.086	.052	.008
13	.103	.098	.062	.080	.099	.080	.092	.072	.062	.045	.047	.096	.000	.054	.008
14	.101	.096	.063	.077	.097	.077	.090	.067	.065	.048	.050	.082	.075	.000	.013
15	.092	.087	.062	.069	.085	.070	.080	.061	.067	.055	.062	.073	.066	.072	.000

1-FATHER, 2-MOTHER, 3-OLDER BROTHERS AND SISTERS, 4-COUSINS, 5-AUNTS, UNCLES, GRANDPARENTS, 6-HIGH SCHOOL FRIENDS, 7-COLLEGE FRIENDS, 8-HIGH SCHOOL COUNSELOR, 9-HIGH SCHOOL PRINCIPAL AND TEACHERS, 10-EMPLOYERS AND COWORKERS, 11-RELIGIOUS LEADER, 12-FAMILY DOCTOR, 13-NEIGHBORS, 14-BROTHER AND SISTER FRIENDS, 15-OTHERS

probability of talking with only one source is zero or very close to zero. However, the Markov chain is a regular chain since this matrix raised to the fourth power contains only positive elements. This stable matrix is shown in Table 2. Each row of this stable matrix is the same vector V such that $V \cdot C = V$. According to the Markov theory no matter what the initial values of the probability vector, the Markov chain will converge to a stable vector V. The convergence of the Markov chain using the transition matrix C is shown in Table 3 where the initial vector contained equally probable elements.

There exist differences at the thousandth position between the percentages of the stable vector at time point six in Table 3 and the percentages in any row vector in Table 2. This can be attributed to accumulated round-off error in multiplication. Therefore, the probability of talking with 1) father, 2) mother, 3) brothers and sisters, 4) cousins, 5) aunts, uncles, grandparents, 6) high school friends, 7) college friends, 8) high school counselor, 9) high school principal and teachers, 10) employers and coworkers, 11) minister, priest, rabbi, 12) the family doctor, 13) neighbors, 14) friends of older brothers and sisters, and 15 other adults over time is shown in Table 3. These two above examples illustrate the manner in which a Markov chain with a stationary transition matrix can be defined and constructed.

A Markov chain can be used to describe a decision-making process such as a student's decision to go to college or not. In general a finite vector A can be defined where each element a_i $(i = 1,2, . . . ,m)$ is a possible alternative open to a decision maker, i.e., $A = (a_1\ a_2\ . . .\ a_m)$. Associated with each a_i is an element p_i which is the probability that alternative i will be chosen by the decision maker. Any p_i is greater

TABLE 2

STABLE MATRIX V--SOURCE TO SOURCE PROBABILITIES
(COMBINED 1962-1963 RESPONSES)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
2	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
3	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
4	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
5	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
6	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
7	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
8	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
9	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
10	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
11	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
12	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
13	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
14	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009
15	.094	.090	.061	.075	.091	.075	.085	.066	.061	.045	.048	.078	.069	.050	.009

1-FATHER, 2-MOTHER, 3-OLDER BROTHERS AND SISTERS, 4-COUSINS, 5-AUNTS, UNCLES, GRANDPARENTS, 6-HIGH SCHOOL FRIENDS, 7-COLLEGE FRIENDS, 8-HIGH SCHOOL COUNSELOR, 9-HIGH SCHOOL PRINCIPAL AND TEACHERS, 10-EMPLOYERS AND COWORKERS, 11-RELIGIOUS LEADER, 12-FAMILY DOCTOR, 13-NEIGHBORS, 14-BROTHER AND SISTER FRIENDS, 15-OTHERS

TABLE 3

MARKOV CHAIN--PROBABILITY OF STUDENT AND SOURCE CONTACT AFTER SIX TIME EVENTS

TIME EVENT	INTERPERSONAL SOURCES 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	.067	.066	.066	.066	.066	.066	.066	.066	.066	.066	.066	.066	.066	.066	.066
1	.095	.091	.059	.074	.091	.074	.085	.065	.061	.045	.048	.077	.068	.050	.009
2	.093	.090	.060	.074	.090	.075	.085	.066	.060	.045	.048	.077	.069	.050	.009
3	.093	.090	.060	.074	.090	.075	.085	.066	.060	.045	.048	.077	.069	.050	.009
4	.093	.090	.060	.074	.090	.075	.085	.066	.060	.045	.048	.077	.069	.050	.009
5	.093	.090	.060	.074	.090	.075	.085	.066	.060	.045	.048	.077	.069	.050	.009
6	.093	.090	.060	.074	.090	.075	.085	.066	.060	.045	.048	.077	.069	.050	.009

1-FATHER, 2-MOTHER, 3-OLDER BROTHERS AND SISTERS, 4-COUSINS, 5-AUNTS, UNCLES, GRANDPARENTS, 6-HIGH SCHOOL FRIENDS, 7-COLLEGE FRIENDS, 8-HIGH SCHOOL COUNSELOR, 9-HIGH SCHOOL PRINCIPAL AND TEACHERS, 10-EMPLOYERS AND COWORKERS, 11-RELIGIOUS LEADER, 12-FAMILY DOCTOR, 13-NEIGHBORS, 14-BROTHER AND SISTER FRIENDS, 15-OTHERS

than or equal to zero and less than or equal to one, i.e., $0 \leq P \leq 1$. Therefore, a vector P which is called a decision vector is defined such that $P = (P_1\ P_2\ .\ .\ .\ P_m)$. The set of elements in A is assumed mutually inclusive or to contain all possible alternatives open to the decision maker. Vector A is also assumed to be mutually exclusive such that no two alternatives can be selected simultaneously. Both assumptions suggest that the sum of the elements in P is equal to one, i.e., $\sum_{i=1}^{m} p_i = 1$.

If the decision vector P is allowed to change over time, it becomes part of a stochastic process. This means that vector P is non-stationary or that the elements p_i can change over time such that $P^{(t)}$ (vector P at time t) is not necessarily equal to $P^{(t+k)}$ (vector P at time t+k). As with previous examples time is assumed discrete. A set T can be defined with elements t such that $t = 0,1,2, . . . ,n$ where n is finite. The elements of T do not have to be measured in any traditional metric such as seconds, days, or months (even though they may well be), for they may represent events or situations. For example, one might define the set T such that each element t represents an increment in the highway death total, and t increases one unit each time a person is killed on the highway. Using the decision model to describe a high school student's decision, the set T can be defined as communication increments such that whenever a student talks with a person the previous time element t is increased one unit, i.e., t+1. In both cases the value of any element t denotes a particular situation, e.g., where 10 people have been killed on the highway or 10 communication contacts made by a high school student.

Changes in P over time are assumed related to some stimuli to which the decision maker is subjected, e.g., at some point the probability that an industrial decision maker will select any alternative could be affected by a gain or loss of money, a gain of new information, or some change in the economic community. The effect of stimuli on the probability of selecting any alternative in the set A can be described by the effect of an operator Q such that $P^{(t)} \cdot Q = P^{(t+1)}$. This means that the probability of any alternative being selected by the decision maker at some point in time t+1 or $p_i^{(t+1)}$ is determined by the effect of an operator Q on the probability of the alternative at the previous time step t or $p_i^{(t)}$.

Any operation on a set of elements can be thought of as a collection of rules, laws, or principles which transforms the elements of the set into another set. More formally this transformation is an assignment to each ordered subset of elements of the original set S a uniquely determined subset of S.[44] For example, the operators of addition and multiplication, for which the symbols "+" and "." are often used, when applied to a subset of the natural numbers give results which are also natural numbers.

In general an operation involves three elements:

(1) An operand or the entity to be transformed is necessary. The collection of entities may be a set of numbers, biological organisms as in biology, matter and energy as in physics, etc. Davis has noted that while human behavior is studied in such scientific disciplines as physiology, psychology,

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[44] J. Fang, Theory and Problems of Abstract Algebra (New York: Schaum Publishing Co., 1963), p. 31. Davis similarly defined an operator as specifying the existence of a "law of transformation whereby one or more members of a set would be transformed into one or more members of a second set." Harold T. Davis, The Theory of Linear Operators (Bloomington, Ind.: The Principia Press, 1936), p. 3.

biology, and economics, the behavior attributes on which each field concentrates delineates the fields and their subject matter. "To put the matter more precisely, we specialize our sciences in terms of the operations which we propose to apply to the objects of our study," Davis said.[45]

(2) The operator is that which represents the rules of transformation. The operator specifies what transformation is to be performed on the operand. This might include addition and multiplication as in arithmetic, differentiation and integration as in calculus, stimuli as in psychology, compound mixing as in chemistry, etc.

(3) The result of the operation is the transform. This includes the responses to the stimuli in a psychological experiment, the sum obtained by addition, the function which comes from integration, etc.[46]

From this discussion it is clear that any mathematical manipulation is a member of the general collection of operations. The operator proposed by this model of decision-making is one which transforms the probabilities at a given time step in the ongoing decision process into the probabilities in the next time step. The problem is one of specifying the operator such that given values at step t the values at step t+1 can be achieved. This is not unlike a "black box" operator. The problem is one of identification where given the input (in this case $P^{(t)}$) and the desired output (the values of $P^{(t+i)}$ the researcher must find the operator which will perform this transformation.[47]

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[45] Davis, op. cit., p. 5.

[46] Ibid., p. 6.

[47] William H. Huggins, "Systems Dynamics," Operations Research and Systems Engineering, eds. S. Flagle, W. Huggins, and R. Roy (Baltimore: The Johns Hopkins Press, 1960), pp. 638-40.

Operator Q performs its transformation through matrix multiplication. Because of the nature of the operator, $P^{(t)} \cdot Q = P^{(t+1)}$ and $(P^{(t+1)} \cdot Q)\,Q = P^{(t+1)} \cdot Q^2$. The operator Q is linear or distributive. That is, it fulfills two conditions: 1) $(P^{(k)} + P^{(j)}) \cdot Q = P^{(k)} \cdot Q + P^{(j)} \cdot Q$ and 2) $aP^{(t)} \cdot Q = P^{(t)} \cdot aQ$. Here k and j are any time elements, and a is any scaler constant.[48]

Since the decision model as defined above contains a probabilistic element and since the process contains no memory where the future is independent of the formation of the past, the decision model is Markovian. This suggests that the transition matrix in a Markov chain can be thought of as a matrix operator which fulfills equation 12. Since a matrix operator can transform an entire set of variables, the matrix operator in a Markov chain can alter all probabilities in the decision vector P simultaneously.

The simplest decision model using the Markov chain principle would involve a transformation matrix with constant probabilities. In the case of a high school student, we will limit the decision alternatives to two, i.e., going or not going to college. The decision set A would contain two elements, a_1 and a_2, where alternative a_1 is "going to college" and alternative a_2 is "not going to college." The transition matrix Q contains four elements and is represented as

$$Q = \begin{array}{cc} \hline q_{11} & q_{12} \\ q_{21} & q_{22} \\ \hline \end{array}$$

In this matrix q_{12} is the probability of changing a going-to-college decision to a not-going-to-college decision, q_{21} is the probability of changing a not-going-to-college decision to a

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[48] Davis, _op. cit._, p. 6.

going-to-college decision, and q_{11} and q_{22} are the probabilities that the decision going-to-college and not-going-to-college, respectively, will be maintained.

Certain assumptions are basic to the development of this decision model. First, this decision process must be relevant to the high school student, i.e., he should have sufficient high school grades and available funds to enter the college-bound stream. The decision as treated by this model is one based on the social impact of the student's environment, for it is assumed that the attitudes of the people who make up the student's communication net affect the student's decision. Arriving at college means that the student made a decision to go to college even though in some few cases the students may have been pressured to go against their will or they just did not care what decision was made. While obtaining information about academic achievement or some other factor which may force the student out of the college-bound stream, this dropout is not part of any voluntary decision reached by the student on his own.

According to the empirical data the probability that any one source will suggest to the student that he do something else other than go to college was .2604 for 1962 and .2357 for 1963 or an average probability for both years of .248. This means the probability that on the average any student who finally arrives at college was discouraged by his interpersonal communication sources approximately 25 per cent of the time. The assumption is made that contact with a person who has an anti-college attitude will increase the probability of a not-going-to-college decision and a positive contact will increase the probability of a going-to-college decision. The probability that a student will change a decision is the probability that this decision will be challenged, and the probability of maintaining a decision is the probability that this decision will be reinforced.

The probability of a not-going-to-college decision being reinforced is .248 and the probability of a going-to-college decision being reinforced is .752. This gives a transition matrix which is represented as

$$Q = \begin{array}{cc} .752 & .248 \\ .752 & .248 \end{array}$$

Matrix Q is part of a regular chain since

$$Q_2 = \begin{array}{cc} .752 & .248 \\ .752 & .248 \end{array} \quad \text{and } Q_3 = \begin{array}{cc} .752 & .248 \\ .752 & .248 \end{array}$$

Since the transition matrix is initially one in which each row vector is identical, all powers of the matrix are the initial matrix again. This transition matrix is one in which the probability of remaining in any state and moving to that state from any other state is the same. This is true since according to the assumptions of the model the probability of a particular alternative being selected is the probability that this alternative will be reinforced.

According to Markov chain theory no matter what the initial vector the process will always converge to a decision vector identical to any row vector in the transition matrix Q. This is shown in Table 4.

TABLE 4

THREE DECISION PROCESSES WITH DIFFERENT INITIAL VALUES

Time State	Case 1		Case 2		Case 3	
0	.900	.100	.500	.500	.300	.700
1	.752	.248	.752	.248	.752	.248
2	.752	.248	.752	.248	.752	.248

No matter what the starting values of the process, the decision vector P converges to the stable vector with elements .752 and .248 or the probabilities of a going-to-college decision and a not-going-to-college decision, respectively. This model provides no additional knowledge about changes in the decision probabilities over time. Since the average number of people with whom the students said they talked was approximately 9 to 10, the model converges independently of the number of reconsiderations any student may have.

The results obtained from this Markov chain suggest four conclusions about a chain with only two possible states. First, any Markov chain which utilizes a transition matrix with equal row vectors will always converge to a probability vector which is equal to any row vector of the transition matrix. No matter what the initial values of the initial probability vector such convergence always occurs in one time step.

Second, a Markov chain with a transition matrix containing four elements which are equally probable will converge to a vector with equally probable states in one step independent of the initial vector. If, for example,

$$P^{(o)} = \overline{\begin{matrix} .001 & .999 \end{matrix}} \quad \text{and} \quad Q = \overline{\underline{\begin{matrix} .500 & .500 \\ .500 & .500 \end{matrix}}}$$

then $P^{(o)} \cdot Q = (.500 \quad .500)$. Third, if the transition matrix is symmetrical and part of a regular chain, the transition matrix raised to the nth power will converge to a matrix with equally probable elements. This means, for example, if

$$Q = \overline{\underline{\begin{matrix} .001 & .999 \\ .999 & .001 \end{matrix}}} \quad \text{and} \quad Q' = \overline{\underline{\begin{matrix} .500 & .500 \\ .500 & .500 \end{matrix}}}$$

then $Q^n \rightarrow Q'$.

Fourth, if the transition matrix is symmetrical and the initial probability vector contains equally probable elements, the decision alternatives will always be equally probable. If

$$Q = \begin{bmatrix} .001 & .999 \\ .999 & .001 \end{bmatrix} \quad \text{and} \quad P^{(o)} = \begin{bmatrix} .500 & .500 \end{bmatrix}$$

then $P^{(o)} \cdot Q = P^{(o)}$ or in general $P^{(t)} \cdot Q = P^{(c)}$.

Because of these conclusions it is clear that such transition matrices are not sufficiently sensitive to measure or predict the outcome of a student's decision relevant to a college career. Since most students arrived at Syracuse University with a pro-college decision, representation of their final decision matrix should be one with complete certainty or near certainty to go to college. The model should provide additional information about selected alternatives other than the data already given empirically. As long as a model of the decision process utilizes a Markov chain which utilizes a stable transition matrix little will be added to our understanding of student decision behavior.

B. Solution Two: A Communication-Decision Model with Time-Varying Parameters or Transformational Behavior Over Time[49]

The Markov chains reviewed and those constructed above utilized constant transition matrices. In many cases writers note that the constant transition matrix is not the best or most accurate matrix operator but that it does make the computation easier and less complex.

Miller in describing the use of finite Markov processes in psychology has noted that while the assumption of a fixed transition matrix greatly simplifies the computation "simplicity is not, however, an intrinsic property of the behavior of living organisms. . . ," he said. Any assumption that a single transition matrix exists also includes the assumption that an animal's course of action or strategy is fixed over time, he added. Miller suggested a search for a matrix function of n, T(n), that changes in some reasonable way over time, if the assumption of a constant transitional matrix seems inappropriate. The initial transitional matrix might be called U and after a sufficient series of states have passed the tendencies represented by U are slowly extinguished and those represented by a second matrix V are strengthened. As an example the following sequence of changes in U can be considered:

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[49] The author is indebted to Dr. Holder (see footnote 1) for his contributions to this phase of model building and in developing out the necessary mathematical expressions.

$$\begin{array}{ll}
T(0) = U & \\
T(1) = wT(0) + (1-w)V & \\
T(2) = wT(1) + (1-w)V & \\
\vdots \qquad \vdots \qquad \vdots & 0 \leq w \leq 1 \\
T(n) = wT(n-1)+(1-w)V. &
\end{array}$$

In this case w represents the preservation of the tendencies on the preceding trial, and (1-w) is the coefficient which moved the initial matrix toward the new mode of response V. When w is near unity, the extinction of the old pattern is slow; if w is near zero, the change is rapid. The above series can be written as:

$$\begin{array}{lll}
T(0) = U & & = w^0 (U-V) + V \\
T(1) = wU + (1-w\ )V & & = w^1 (U-V) + V \\
T(2) = w^2U+ (1-w^2)V & & = w^2 (U-V) + V \\
T(3) = w\ U+ (1-w\ )V & & = w^3 (U-V) + V \\
\vdots \qquad \vdots \qquad \vdots & & \vdots \qquad \vdots \\
T(n) = w^nU+ (1-w^n)V & & = w^n (U-V) + V.
\end{array}$$

Here T(n) approaches V as n increases since $0 \leq w \leq 1$. If the above series represents a subject who might be in a learning experiment, the more experience the subject has, the less importance U is given in the series. The two matrices U and V, according to Miller, can be computed theoretically or can be determined from data.[50]

In the previous examples of the Markov principle as reviewed in this paper the construction of the stable transition matrix was unique. In most cases once this matrix was formed the outcome of the process was fixed, i.e., over a sufficient number of time states, the process will converge to a stable state. Miller is one of a few behavioral science researchers who have considered the development of a dynamic transitional matrix (that is, a time varying matrix) since the manipulation and construction of a non-stable matrix is difficult.

The previous decision model was a Markov chain with a constant transition matrix which was independent of time such that $Q^{(t)} = Q^{(t+k)}$ or where the element values of the transition matrix Q at time t were the same as the elements of Q at time t+k. A more general model would relax the requirement of a constant operator such that

$$(15) \qquad Q^{(t)} = \begin{matrix} q_{11}^{(t)} & q_{12}^{(t)} \\ q_{21}^{(t)} & q_{22}^{(t)} \end{matrix} \; .$$

In this case $q_{ij}^{(t)}$ is the probability of going from decision i to decision j at time state t. The decision process is now defined as

$$(16) \qquad A^{(t)} \cdot Q^{(t+1)} = A^{(t+1)} \; .$$

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[50] George A. Miller, "Finite Markov Processes in Psychology," Readings in Mathematical Psychology, eds. D. Luce et al., I (New York: John Wiley & Sons, Inc., 1963), pp. 445-47.

The transformation of q_{ij} (the elements of Q) over time can be expressed as $q_{ij}^{(t+1)} = f(q_{ij}^{(t)})$. Here f denotes a function[51] which transforms each element of set $Q^{(t)}$ into a related set $Q^{(t+1)}$. This transformation of any q_{ij} is an attempt to express the effect of some environmental stimuli (in which the student may come in contact) on the student's decision process. As in the previous model with a stable transition matrix the stimuli are the attitudes of the people with whom the student talks about college.

One way of defining the transformation of each q_{ij} has been suggested by McPhee.[52] He defined p as the probability of voting for a cause with which another person disagrees and d as the probability of voting for a cause with which another person agrees, i.e., $p+d=1$. McPhee defined Prob(p;k) as the probability that the voter will persist in a choice disagreeable to others after k reconsiderations. A "reconsideration" in this situation is exposure to a person with whom the voter disagrees in voting preference. Therefore,

$$\begin{aligned} \text{Prob}(p;0) &= p \\ \text{Prob}(p;1) &= p(p) = p^2 \\ \text{Prob}(p;2) &= p(p)^2 = p^3 \\ &\vdots \\ \text{Prob}(p;k) &= p^{k+1} \end{aligned}$$

Defining the change in p in this manner, McPhee noted that the sensitivity of the process is conditioned by the initial disposition. For example, with one reconsideration:

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[51] A function can be defined as a transformation T (or mapping) of a set X into or onto a set Y which assigns to each element x of X a uniquely determined element y of Y. Fang, *op. cit.*, p. 34. In the case of the transition matrix the elements of Q are mapped into elements of another set Q' or the transformation matrix at the next time step.

[52] William N. McPhee, *Formal Theories of Mass Behavior* (New York: The Free Press of Glencoe, 1963), pp. 100-101.

If $p = .20$, then $\text{Prob}(p;1) = .04$ or a reduction of $\frac{4}{5}$
If $p = .80$, then $\text{Prob}(p;1) = .65$ or a reduction of $\frac{1}{5}$
If $p = .50$, then $\text{Prob}(p;1) = .25$ or a reduction of $\frac{1}{2}$.

This analysis of change in voting preference illustrates a possible analysis of change in decision preferences of high school students. A reconsideration can be any discussion by a student with another person about college. Any reconsideration is then an element of the time set T such that t designates the number of reconsiderations experienced by a student.

If a decision alternative is challenged, those elements of the transition matrix which are the probabilities of selection for this alternative will be squared. If, for example, the alternative going-to-college was challenged by some person, the probability of a going-to-college decision will be reduced. Notationally this means

$$Q^{(t+1)} \quad \begin{array}{ll} q_{11}^{(t+1)} = (q_{22}^{(t)})^2 & q_{12}^{(t+1)} = 1-q_{11}^{(t+1)} \\ q_{21}^{(t+1)} = (q_{21}^{(t)})^2 & q_{22}^{(t+1)} = 1-q_{21}^{(t+1)} \end{array} \quad .$$

In this model the more often the student meets someone who suggests he not go to college, the more reduction there is in the probability that this student will make a going-to-college decision.

The same would be true of the probability that the student will maintain a not-going-to-college decision when he comes in contact with a person who encourages him to attend college. Notationally this would be:

$$Q^{(t+1)} \quad \begin{array}{ll} q_{11}^{(t+1)} = 1-q_{12}^{(t+1)} & q_{12}^{(t+1)} = (q_{12}^{(t)})^2 \\ q_{21}^{(t+1)} = 1-q_{22}^{(t+1)} & q_{22}^{(t+1)} = (q_{22}^{(t)})^2 \end{array}$$

In general the probability that a particular alternative will be reinforced at any time t is governed by the attitude of the person with whom the student talks at time t.

A general expression of the transformation of any q_{ij} for any t $(0 \leq t \geq n)$ is

$$q_{ij}^{(t+1)} = (q_{ij}^{(t)})^{1+k} \quad (1+q_{iv}^{(t)})^{1-k} \qquad \text{where } \begin{array}{l} i=1,2, \\ j=1,2 \\ v=1,2 \\ j \neq v \\ i \neq v \end{array}$$

(1) if $i = j$

$$k = \begin{cases} +1 \text{ if state } i \text{ is challenged} \\ 0 \text{ if state } i \text{ is reinforced} \end{cases}$$

(2) if $i \neq j$

$$k = \begin{cases} 0 \text{ if state } i \text{ is challenged} \\ +1 \text{ if state } i \text{ is reinforced.} \end{cases}$$

Specification of Q at any point t+1 requires exact knowledge of the values of the previous reconsideration t and the attitude of the person with whom the student talked at t+1.

If a Markov chain contains a state which is impossible to leave, the chain is absorbing, and the probability that the process will enter this state is one. In the case of a decision process the values of the Markov chain give the probability that the various alternatives will be selected by the decision maker. The more such a process approaches an absorbing state, the more certainty there exists in the model, for if the process is absorbing, then P is a decision vector in which there is no doubt which alternative will be chosen. If the process is converging to an absorbing state, the transition matrix must also be converging to an absorbing matrix since the entire Markov chain revolves around the transition matrix. An absorbing matrix is a matrix where the probability of entering a state from any other state is one and the probability of leaving the state is zero. This would mean that all elements of the ith column would be one, and all other elements of the matrix would be zero. If the going-to-college decision was the absorbing state, the matrix would be

$$\Omega^{(t)} = \begin{matrix} 1.0 & .0 \\ 1.0 & .0 \end{matrix} .$$

If the decision situation does not involve an absorbing matrix or one which closely approximates an absorbing matrix, prediction of the decision is difficult, and there exists uncertainty in the decision process.

VI.

RESULTS: COMPUTER SIMULATION OF COMMUNICATION-DECISION BEHAVIOR

Having developed a Markovan time-varying communication-decision model, it is now possible to simulate college-going behavior among high school students as it possibly may occur in actuality. The social-psychological theory of communication-decision behavior of adolescents who decide to continue or discontinue their education beyond high school may now be reduced to this theoretical statement:

> Each time any decision alternative open to a decision-maker is reinforced by information with which the decision-maker comes in contact through communication, the probability that this alternative will be selected by a decision-maker is increased. And similarly, each time any decision alternative open to a decision-maker is challenged by information obtained by the decision-maker through communication, the probability that this alternative will be selected by the decision-maker is decreased.

One assumption of this theory is that the decision-maker initially establishes a set of probabilities such that each member of the set is related to the selection of one member of an alternative set. This is called the initial impression or disposition, i.e., the initial state of individual I. This state is the value of communication derived from the Ackoff-Martin equation.[53]

In order for the decision-maker to clarify or test these predispositions in terms of validity, reliability, and relevance, he may then be exposed (or expose himself) to the ideas of others through communications. These "ideas" would include sets of alternatives, sets of outcomes or objectives, sets of values or utilities assigned to these outcomes, and sets of efficiencies whereby certain outcomes can be realized from the alternatives.

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[53] The value of a communication is given by the equation $V_c = \sum_{i=1}^{m} \sum_{j=i}^{n} (P_i+\Delta P_i)(E_{ij}+\Delta E_{ij})(V_j+\Delta V_j) - \sum_{i=1}^{m} \sum_{j=i}^{n} P_i E_{ij} V_j$. See Martin, op. cit., in footnote 13.

Communication exposure would include talks, conversations, discussions, and interviews with neighbors, relatives, parents, peers, and the like, as well as reading, hearing, or viewing newspapers, magazines, radio, and television.

As the decision-maker is exposed to others' ideas, the probability that any course of action will be selected is strengthened or weakened by the kind of information-influence input, i.e., communication value.[54]

The computer program was written in FORTRAN language, and the Markov communication-decision model was simulated on the facilities of the Syracuse University Computing Center, the IBM 7074 digital computer system, with the computer providing random information contacts.

The computer generated a number of outcomes which showed 1) how long it took to arrive at a "decision" and 2) what kind of decision was made, namely, to go or not to go to college. The first situation is one in which there is concentrated contact by the high school student with people who can be called pro-college information sources. Their attitudes tend to reinforce the going-to-college alternative, and if sufficient numbers of them are encountered, the student will have little or no uncertainty in making a decision to go to college. Case 1, Table 5, is an example where the student enters the decision process with high probability (a strong tendency) to go to college, and after three communication contacts with others

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[54] See footnote 52.

TABLE 5

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 1

CONTACT NUMBER	TRANSITION MATRIX			CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL- NEG.	-TOTAL- POS.	PROBABILITY VECTOR	
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
0	COLLEGE NOT COLLEGE	0.9000 0.8000	0.1000 0.2000		0.5000	0	0	0.7747	0.2253
1	COLLEGE NOT COLLEGE	0.9900 0.9600	0.0100 0.0400	-POSITIVE-	0.5000	0	1	0.9832	0.0168
2	COLLEGE NOT COLLEGE	0.9999 0.9984	0.0001 0.0016	-POSITIVE-	0.5000	0	2	0.9999	0.0001
3	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-POSITIVE-	0.5000	0	3	1.0000	0.0000
4	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-POSITIVE-	0.5000	0	4	1.0000	0.0000
5	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-POSITIVE-	0.5000	0	5	1.0000	0.0000
6	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-POSITIVE-	0.5000	0	6	1.0000	0.0000
7	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-NEGATIVE-	0.5000	1	6	1.0000	0.0000
8	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-NEGATIVE-	0.5000	2	6	1.0000	0.0000
9	COLLEGE NOT COLLEGE	1.0000 1.0000	0.0000 0.0000	-NEGATIVE-	0.5000	3	6	1.0000	0.0000

(reinforcements) the transition matrix moves to an absorbing matrix where the probability of maintaining a going-to-college decision and moving to a going-to-college decision is one. Of the 1,967 Syracuse University freshmen who answered the questionnaire in 1962 some 1,478 of them said they had always planned to go to college and never had any doubts about it. Case 1 is an illustration of their possible decision behavior in which once they entered the going-to-college stream they never left it. Such an accumulation of pro-college contacts agrees with previous research conclusions which have noted that once a person has an attitude (or in this case a preference) about something, he seeks others who will reinforce this attitude. The responses obtained from Syracuse University freshmen indicated that only 25 per cent of the people with whom the freshmen talked while still high school students suggested they not go to college.

Of the students who answered the questionnaire in 1962, 16 said while they were in high school they did not want to go to college. Since they arrived at college, this attitude may have been altered. Case 2, Table 6, is an example of a student who has a strong preference for a not-going-to-college decision, but through parental pressure, peer group contact, or other communication contacts which are consistently pro-college, the attitude of the student is shifted until he reaches a going-to-college decision. In this case some 15 reconsiderations were required in which almost 70 per cent or two-thirds of the contacts were pro-college. The student's original tendency against college is slow to change, but under constant challenge a shift in tendency is achieved.

Case 3, Table 7, illustrates the effect of concentrated exposure to people who are pro-college when the student is initially undecided either way. In Case 1 and Case 3 the transition

TABLE 6

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 2

CONTACT NUMBER	TRANSITION MATRIX			CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL-		PROBABILITY VECTOR	
		COLLEGE	NOT COLLEGE			NEG.	POS.	COLLEGE	NOT COLLEGE
0	COLLEGE	0.1000	0.9000		0.5000	0	0	0.7584	0.2416
	NOT COLLEGE	0.3000	0.7000						
1	COLLEGE	0.1900	0.8100	-POSITIVE-	0.5000	0	1	0.2673	0.7327
	NOT COLLEGE	0.5100	0.4900						
2	COLLEGE	0.3439	0.6561	-POSITIVE-	0.5000	0	2	0.6487	0.3513
	NOT COLLEGE	0.7599	0.2401						
3	COLLEGE	0.1183	0.8017	-NEGATIVE-	0.5000	1	2	0.2796	0.7204
	NOT COLLEGE	0.5774	0.4226						
4	COLLEGE	0.2225	0.7775	-POSITIVE-	0.5000	1	3	0.6540	0.3460
	NOT COLLEGE	0.8214	0.1786						
5	COLLEGE	0.3956	0.6044	-POSITIVE-	0.5000	1	4	0.5937	0.4063
	NOT COLLEGE	0.9681	0.0319						
6	COLLEGE	0.6347	0.3653	-POSITIVE-	0.5000	1	5	0.7827	0.2173
	NOT COLLEGE	0.9990	0.0010						
7	COLLEGE	0.4028	0.5972	-NEGATIVE-	0.5000	2	5	0.5321	0.4679
	NOT COLLEGE	0.9980	0.0020						
8	COLLEGE	0.6433	0.3567	-POSITIVE-	0.5000	2	6	0.8102	0.1898
	NOT COLLEGE	1.0000	0.0000						
9	COLLEGE	0.8728	0.1272	-POSITIVE-	0.5000	2	7	0.8969	0.1031
	NOT COLLEGE	1.0000	0.0000						
10	COLLEGE	0.9838	0.0162	-POSITIVE-	0.5000	2	8	0.9855	0.0145
	NOT COLLEGE	1.0000	0.0000						
11	COLLEGE	0.9679	0.0321	-NEGATIVE-	0.5000	3	8	0.9684	0.0316
	NOT COLLEGE	1.0000	0.0000						
12	COLLEGE	0.9990	0.0010	-POSITIVE-	0.5000	3	9	0.9990	0.0010
	NOT COLLEGE	1.0000	0.0000						
13	COLLEGE	0.9979	0.0021	-NEGATIVE-	0.5000	4	9	0.9979	0.0021
	NOT COLLEGE	1.0000	0.0000						
14	COLLEGE	0.9959	0.0041	-NEGATIVE-	0.5000	5	9	0.9959	0.0041
	NOT COLLEGE	1.0000	0.0000						
15	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	5	10	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
16	COLLEGE	1.0000	0.0000	-NEGATIVE-	0.5000	6	10	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
17	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	6	11	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
18	COLLEGE	1.0000	0.0000	-NEGATIVE-	0.5000	7	11	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
19	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	7	12	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						

TABLE 7

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 3

CONTACT NUMBER	TRANSITION MATRIX			CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL-		PROBABILITY VECTOR	
		COLLEGE	NOT COLLEGE			NEG.	POS.	COLLEGE	NOT COLLEGE
0	COLLEGE	0.4500	0.5500		0.5000	0	0	0.0830	0.9170
	NOT COLLEGE	0.5600	0.4400						
1	COLLEGE	0.6975	0.3025	-POSITIVE-	0.5000	0	1	0.7974	0.2026
	NOT COLLEGE	0.8064	0.1936						
2	COLLEGE	0.4865	0.5135	-NEGATIVE-	0.5000	1	1	0.5197	0.4803
	NOT COLLEGE	0.6503	0.3497						
3	COLLEGE	0.7363	0.2637	-POSITIVE-	0.5000	1	2	0.8042	0.1958
	NOT COLLEGE	0.8777	0.1223						
4	COLLEGE	0.9305	0.0695	-POSITIVE-	0.5000	1	3	0.9412	0.0588
	NOT COLLEGE	0.9850	0.0150						
5	COLLEGE	0.9952	0.0048	-POSITIVE-	0.5000	1	4	0.9954	0.0046
	NOT COLLEGE	0.9998	0.0002						
6	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	1	5	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
7	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	1	6	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
8	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	1	7	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						
9	COLLEGE	1.0000	0.0000	-POSITIVE-	0.5000	1	8	1.0000	0.0000
	NOT COLLEGE	1.0000	0.0000						

matrix converged quickly to an absorbing matrix, and once stable it is not affected by any further communication contacts.

Such rapid convergence suggests that the sooner a person talks with a student and the weaker his disposition toward a decision alternative, the more impact (or "influence") this person will have on the student's decision. The smaller the probability of any alternative the more this probability is weakened if it is challenged, but once the decision vector begins to converge to an absorbing matrix, that is, the stronger the preferences, the harder it is for one opposing contact to check this convergence. The strength of any one communication source is increased by the number of other sources with similar attitudes who talk with the student in a series of communication contacts.

Case 4, Table 8, illustrates the situation of a high school student who has a predisposition not to go to college and who maintains this tendency because of constant reinforcement from his environment. In this example, the transition matrix does not converge to an absorbing matrix until the eighth reconsideration because three of the people with whom the student talked encouraged him to go to college. However, the strong initial disposition and the reinforcement this disposition obtains from the student's communication net is difficult to overcome.

As illustrated by Case 2 if considerable pressure against an alternative is exerted, even a strong initial tendency toward this alternative can be weakened until the tendency has completely shifted. Case 5, Table 9, might illustrate the situation of a bright high school student who would like to go to college but who is discouraged from going on for advanced education by his parents (who did not go to college) and his friends (who do not intent to attend college) and others. The student's "advisors" may think a college education is a "waste of time" or for kids

TABLE 8

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 4

CONTACT NUMBER	TRANSITION MATRIX	CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL- NEG.	-TOTAL- POS.	PROBABILITY VECTOR
0	COLLEGE NOT COLLEGE COLLEGE 0.1000 0.9000 NOT COLLEGE 0.3000 0.7000		0.5000	0	0	COLLEGE NOT COLLEGE 0.5988 0.4012
1	COLLEGE NOT COLLEGE COLLEGE 0.1900 0.8100 NOT COLLEGE 0.5100 0.4900	-POSITIVE-	0.5000	0	1	COLLEGE NOT COLLEGE 0.3184 0.6816
2	COLLEGE NOT COLLEGE COLLEGE 0.0361 0.9639 NOT COLLEGE 0.2601 0.7399	-NEGATIVE-	0.5000	1	1	COLLEGE NOT COLLEGE 0.1888 0.8112
3	COLLEGE NOT COLLEGE COLLEGE 0.0709 0.9291 NOT COLLEGE 0.4525 0.5475	-POSITIVE-	0.5000	1	2	COLLEGE NOT COLLEGE 0.3805 0.6195
4	COLLEGE NOT COLLEGE COLLEGE 0.0050 0.9950 NOT COLLEGE 0.2048 0.7952	-NEGATIVE-	0.5000	2	2	COLLEGE NOT COLLEGE 0.1288 0.8712
5	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.0419 0.9581	-NEGATIVE-	0.5000	3	2	COLLEGE NOT COLLEGE 0.0365 0.9635
6	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.0018 0.9982	-NEGATIVE-	0.5000	4	2	COLLEGE NOT COLLEGE 0.0017 0.9983
7	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.0035 0.9965	-POSITIVE-	0.5000	4	3	COLLEGE NOT COLLEGE 0.0035 0.9965
8	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.0000 1.0000	-NEGATIVE-	0.5000	5	3	COLLEGE NOT COLLEGE 0.0000 1.0000
9	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.0000 1.0000	-POSITIVE-	0.5000	5	4	COLLEGE NOT COLLEGE 0.0000 1.0000

TABLE 9

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 5

CONTACT NUMBER	TRANSITION MATRIX			CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL-		PROBABILITY VECTOR	
		COLLEGE	NOT COLLEGE			NEG.	POS.	COLLEGE	NOT COLLEGE
0	COLLEGE	0.9000	0.1000		0.5000	0	0	0.2302	0.7698
	NOT COLLEGE	0.8000	0.2000						
1	COLLEGE	0.8100	0.1900	-NEGATIVE-	0.5000	1	0	0.6791	0.3209
	NOT COLLEGE	0.6400	0.3600						
2	COLLEGE	0.6561	0.3439	-NEGATIVE-	0.5000	2	0	0.5770	0.4230
	NOT COLLEGE	0.4096	0.5904						
3	COLLEGE	0.4305	0.5695	-NEGATIVE-	0.5000	3	0	0.3193	0.6807
	NOT COLLEGE	0.1678	0.8322						
4	COLLEGE	0.1853	0.8147	-NEGATIVE-	0.5000	4	0	0.0783	0.9217
	NOT COLLEGE	0.0281	0.9719						
5	COLLEGE	0.0343	0.9657	-NEGATIVE-	0.5000	5	0	0.0034	0.9966
	NOT COLLEGE	0.0008	0.9992						
6	COLLEGE	0.0012	0.9988	-NEGATIVE-	0.5000	6	0	0.0000	1.0000
	NOT COLLEGE	0.0000	1.0000						
7	COLLEGE	0.0024	0.9976	-POSITIVE-	0.5000	6	1	0.0000	1.0000
	NOT COLLEGE	0.0000	1.0000						
8	COLLEGE	0.0000	1.0000	-NEGATIVE-	0.5000	7	1	0.0000	1.0000
	NOT COLLEGE	0.0000	1.0000						
9	COLLEGE	0.0000	1.0000	-POSITIVE-	0.5000	7	2	0.0000	1.0000
	NOT COLLEGE	0.0000	1.0000						

only from "fancy neighborhoods." This is the phenomenon of the young person who wishes to rise above his home environment but is unable to because of the pressure exerted by his environment.

Case 6, Table 10, is the mirror image of Case 3 where the student is initially undecided about a decision to go to college. However, under a constant stream of anti-college contacts the student moves toward a decision not to go to college. This might illustrate the situation of a student who may be undecided because he experiences no definite push from his environment toward either alternative. Then the student's environment changes. This might occur if the student and his family were to move to a new town or to a new neighborhood where the attitudes of the community are very distinctly anti-college. Influenced by this new environment the student rapidly becomes anti-college himself.

Case 7, Table 11, is a unique decision-making situation. The student initially begins with the same transition probabilities as Case 6. By the ninth reconsideration the student has been exposed to five anti-college and four pro-college sources. The influentials tend to balance the effect of one another, and the transition matrix illustrates the impact of a series of balanced contacts. This balancing continues until the 23rd reconsideration where the decision process reaches a stable state. However, this is not an absorbing state since the probability of moving from a state to a different state is one and the probability of remaining in any state is zero. In this situation the student is still undecided whether to go or not to go to college. We can assume that a student who experiences this pattern of influence from his social environment will have great difficulty making a decision about college as he has no constant direction or pressure toward either alternative.

These seven cases are examples of the behavior of the model as it operates on sets of data. These cases illustrate some hypothesized situations of high school students attempting to make some decision about college.

TABLE 10

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 6

CONTACT NUMBER	TRANSITION MATRIX			CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL-		PROBABILITY VECTOR	
						NEG.	POS.		
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
0	COLLEGE	0.4500	0.5500		0.5000	0	0	0.3399	0.6601
	NOT COLLEGE	0.5600	0.4400						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
1	COLLEGE	0.2025	0.7975	-NEGATIVE-	0.5000	1	0	0.2758	0.7242
	NOT COLLEGE	0.3136	0.6864						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
2	COLLEGE	0.0410	0.9590	-NEGATIVE-	0.5000	2	0	0.0825	0.9175
	NOT COLLEGE	0.0983	0.9017						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
3	COLLEGE	0.0803	0.9197	-POSITIVE-	0.5000	2	1	0.1782	0.8218
	NOT COLLEGE	0.1870	0.8130						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
4	COLLEGE	0.1542	0.8458	-POSITIVE-	0.5000	2	2	0.3061	0.6939
	NOT COLLEGE	0.3391	0.6609						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
5	COLLEGE	0.0238	0.9762	-NEGATIVE-	0.5000	3	2	0.0870	0.9130
	NOT COLLEGE	0.1150	0.8850						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
6	COLLEGE	0.0006	0.9994	-NEGATIVE-	0.5000	4	2	0.0121	0.9879
	NOT COLLEGE	0.0132	0.9868						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
7	COLLEGE	0.0000	1.0000	-NEGATIVE-	0.5000	5	2	0.0002	0.9998
	NOT COLLEGE	0.0002	0.9998						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
8	COLLEGE	0.0000	1.0000	-POSITIVE-	0.5000	5	3	0.0003	0.9997
	NOT COLLEGE	0.0003	0.9997						
		COLLEGE	NOT COLLEGE					COLLEGE	NOT COLLEGE
9	COLLEGE	0.0000	1.0000	-NEGATIVE-	0.5000	6	3	0.0000	1.0000
	NOT COLLEGE	0.0000	1.0000						

TABLE 11

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 7

```
CONTACT                                     CONTACT       CONTACT             -TOTAL-              PROBABILITY
NUMBER          TRANSITION MATRIX           ATTITUDE      PROBABILITY         NEG.   POS.             VECTOR
------------------------------------------------------------------------------------------------------------------

                    COLLEGE  NOT COLLEGE
  0        COLLEGE 0.4500     0.5500                       0.5000              0      0        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.5600     0.4400                                                           0.8160    0.1840

                    COLLEGE  NOT COLLEGE
  1        COLLEGE 0.6975     0.3025        -POSITIVE-     0.5000              0      1        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.8064     0.1936                                                           0.7175    0.2825

                    COLLEGE  NOT COLLEGE
  2        COLLEGE 0.4865     0.5135        -NEGATIVE-     0.5000              1      1        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.6503     0.3497                                                           0.5328    0.4672

                    COLLEGE  NOT COLLEGE
  3        COLLEGE 0.7363     0.2637        -POSITIVE-     0.5000              1      2        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.8777     0.1223                                                           0.8024    0.1976

                    COLLEGE  NOT COLLEGE
  4        COLLEGE 0.5422     0.4578        -NEGATIVE-     0.5000              2      2        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.7704     0.2296                                                           0.5873    0.4127

                    COLLEGE  NOT COLLEGE
  5        COLLEGE 0.2940     0.7060        -NEGATIVE-     0.5000              3      2        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.5934     0.4066                                                           0.4176    0.5824

                    COLLEGE  NOT COLLEGE
  6        COLLEGE 0.5015     0.4985        -POSITIVE-     0.5000              3      3        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.8347     0.1653                                                           0.6956    0.3044

                    COLLEGE  NOT COLLEGE
  7        COLLEGE 0.2515     0.7485        -NEGATIVE-     0.5000              4      3        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.6967     0.3033                                                           0.3870    0.6130

                    COLLEGE  NOT COLLEGE
  8        COLLEGE 0.0633     0.9367        -NEGATIVE-     0.5000              5      3        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.4854     0.5146                                                           0.3220    0.6780

                    COLLEGE  NOT COLLEGE
  9        COLLEGE 0.1225     0.8775        -POSITIVE-     0.5000              5      4        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.7352     0.2648                                                           0.5379    0.4621

                    COLLEGE  NOT COLLEGE
 10        COLLEGE 0.0150     0.9850        -NEGATIVE-     0.5000              6      4        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.5406     0.4594                                                           0.2579    0.7421

                    COLLEGE  NOT COLLEGE
 11        COLLEGE 0.0002     0.9998        -NEGATIVE-     0.5000              7      4        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.2922     0.7078                                                           0.2169    0.7831

                    COLLEGE  NOT COLLEGE
 12        COLLEGE 0.0005     0.9995        -POSITIVE-     0.5000              7      5        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.4990     0.5010                                                           0.3909    0.6091

                    COLLEGE  NOT COLLEGE
 13        COLLEGE 0.[illegible]9     0.9991        -POSITIVE-     0.5000              7      6        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.[illegible]0     0.2510                                                           0.4566    0.5434

                    COLLEGE  NOT COLLEGE
 14        COLLEGE 0.0018     0.9982        -POSITIVE-     0.5000              7      7        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9370     0.0630                                                           0.5100    0.4900

                    COLLEGE  NOT COLLEGE
 15        COLLEGE 0.0036     0.9964        -POSITIVE-     0.5000              7      8        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9960     0.0040                                                           0.4899    0.5101

                    COLLEGE  NOT COLLEGE
 16        COLLEGE 0.0000     1.0000        -NEGATIVE-     0.5000              8      8        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9921     0.0079                                                           0.5061    0.4939

                    COLLEGE  NOT COLLEGE
 17        COLLEGE 0.0000     1.0000        -NEGATIVE-     0.5000              9      8        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9842     0.0158                                                           0.4861    0.5139

                    COLLEGE  NOT COLLEGE
 18        COLLEGE 0.0000     1.0000        -NEGATIVE-     0.5000             10      8        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9687     0.0313                                                           0.4978    0.5022

                    COLLEGE  NOT COLLEGE
 19        COLLEGE 0.0000     1.0000        -NEGATIVE-     0.5000             11      8        COLLEGE  NOT COLLEGE
       NOT COLLEGE 0.9384     0.0616                                                           0.4713    0.5287
```

TABLE 11--Continued

DECISION MODEL WITH A TIME VARYING TRANSITION MATRIX--CASE 7

CONTACT NUMBER	TRANSITION MATRIX	CONTACT ATTITUDE	CONTACT PROBABILITY	-TOTAL- NEG.	-TOTAL- POS.	PROBABILITY VECTOR
20	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.9962 0.0038	-POSITIVE-	0.5000	11	9	COLLEGE NOT COLLEGE 0.5267 0.4733
21	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.9924 0.0076	-NEGATIVE-	0.5000	12	9	COLLEGE NOT COLLEGE 0.4697 0.5303
22	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 0.9999 0.0001	-POSITIVE-	0.5000	12	10	COLLEGE NOT COLLEGE 0.5303 0.4697
23	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-POSITIVE-	0.5000	12	11	COLLEGE NOT COLLEGE 0.4697 0.5303
24	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-NEGATIVE-	0.5000	13	11	COLLEGE NOT COLLEGE 0.5303 0.4697
25	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-POSITIVE-	0.5000	13	12	COLLEGE NOT COLLEGE 0.4697 0.5303
26	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-POSITIVE-	0.5000	13	13	COLLEGE NOT COLLEGE 0.5303 0.4697
27	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-POSITIVE-	0.5000	13	14	COLLEGE NOT COLLEGE 0.4697 0.5303
28	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-NEGATIVE-	0.5000	14	14	COLLEGE NOT COLLEGE 0.5303 0.4697
29	COLLEGE NOT COLLEGE COLLEGE 0.0000 1.0000 NOT COLLEGE 1.0000 0.0000	-POSITIVE-	0.5000	14	15	COLLEGE NOT COLLEGE 0.4697 0.5303

VII.

CONCLUSION

The many factors which seem pertinent to a high school student's decision to go to college suggest that the communication in which a student is involved in reaching a decision is a complex activity. The assumptions upon which the mathematical model proposed by this study rests and the simplicity of the model prevent it from being a strong predictive or realistic representation of adolescent decision-making. Nevertheless, the model does suggest a way to conceptualize this decision process and provides a basic framework upon which more realistic models might be constructed. The empirical data make it clear that a student's decision is affected by both the attitudes of the people with whom the student talks and the information about a college education he obtains from them. Of course, by the definition of information used by this study, knowledge about the attitude of any person is also information. But knowledge about the availability of money for expenses, the academic ability of the student for college work, and other factors is also necessary for decision-making.

This model utilizes the Markov principle and predicts decision behavior which generally fits the patterns demonstrated by the empirical conclusions of the data. The transformation of the transition matrix at each reconsideration is an approach to the way in which a real decision system may behave. Actually it is this transformation which is the heart of the model, and the more accurate this transformation, the better prediction the model can give.

Simulation of the adolescent decision process by using this model gives outcomes which intuitively fit or portray the actual decision process of high school students under varying communication environments. Changes in the decision tendencies of the model are gradual. This illustrates the point that changes in attitude or preference do not occur instantly. Rather the decision process takes slow steps toward an absorbing state. In this model the influence or impact of any one communication contact with a high school student is related to the number of other contacts the student makes which have a similar attitude. The contact which eventually pushes the decision process into a state of certainty makes a very minor change in the alternative probabilities.

The transition matrix converges in some cases to an absorbing matrix which remains unchanged no matter what the attitudes with which the student may come in contact. While the transformation of matrix Q as defined by this study appears proper, it may converge more rapidly than an actual decision process. The nature of the absorbing matrix prevents the character of the model from changing once it has converged to an absorbing state. This inflexibility is a weakness in the predictive ability of the model. However, the number of reconsiderations necessary for convergence to an absorbing state falls within the number of communication contacts reported by the students. Since most students who arrived at Syracuse University had little uncertainty about their decision, the absorbing chain seems a good representation of their decision vector.

A more general decision model could relax the requirement of a dichotomous decision situation to include more of the alternatives open to a high school student. Increasing the size of the decision vector would obviously increase the complexity of manipulation, but such a model would be a more realistic attack on the problem of understanding adolescent decision behavior.